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GLOBE WEATHER



THE GLOBE PROGRAM



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TEACHER GUIDE



THE GLOBE PROGRAM

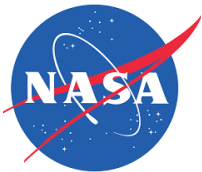


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OVERVIEW OF GLOBE WEATHER



THE GLOBE PROGRAM

Overview of GLOBE Weather

With GLOBE Weather, middle school students explore phenomena related to weather and storms during a five-week unit to help them understand weather at local, regional, and global scales. They analyze weather data collected at schools that are a part of the [GLOBE Program](http://www.globe.gov) (www.globe.gov), and they make their own observations of weather following GLOBE Atmosphere Protocols.

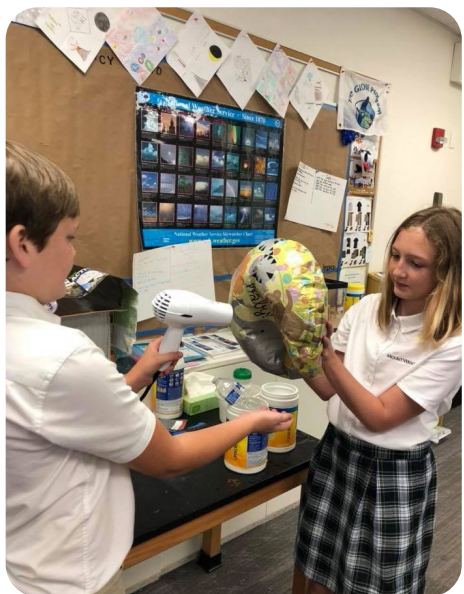
The GLOBE Weather curriculum has been developed to directly address Next Generation Science Standards focusing on student explorations of weather phenomena and utilizing a storyline approach within three 5E learning cycles (Bybee, et al., 2006). The curriculum has a particular focus on analysis and interpretation of weather data and iterative development of models to explain and document student understandings. Avenues for further explorations of weather with the GLOBE Program provide opportunities to extend student learning with research projects.

STORYLINE APPROACH

GLOBE Weather uses a storyline instructional approach to help sequence learning and flow logically for students from beginning to end. The intent of a storyline is to make the unit's lessons coherent from the student perspective. Students know what they are working on and why as they go through the unit. GLOBE Weather focuses on questions in each lesson, rather than topics, in order to provide students with motivation for each lesson and to keep the focus on exploration and discovery.

The instructional supports provided in the teacher instructions are intended to help you in make the storyline clear to students throughout the unit. The class as a whole develops ideas over time, motivated by questions about weather phenomena. Throughout the unit, the story of weather unfolds gradually. Individual lessons address a particular question and, over time, understanding builds. The storyline approach supports students' agency in sensemaking, allowing them to figure out science ideas and put them together over time.

A FOCUS ON WEATHER PHENOMENA



Students experiment with air temperature and movement during GLOBE Weather Lesson 5. (Courtesy: Susan Oltman)



Thunderstorm (Courtesy: Bob Henson, UCAR)

Interesting phenomena are key to the storyline approach. It might be a surprising or puzzling phenomenon, something that students have come to accept but cannot explain, like clouds changing shape and size. It might be a phenomenon that students want to be able to predict and prepare for, like a violent storm. Or, it might be an everyday phenomenon that mystifies students when they stop to think about it, like why a small cloud spontaneously appears in a once completely clear sky.

In GLOBE Weather, phenomena are carefully selected to anchor a storyline. The *anchoring phenomenon* for this unit is a precipitation event in which an unusually large amount of precipitation happened in a relatively short amount of time in Colorado (U.S.), in September 2013. Students broaden from this storm event to consider many different types of precipitation events. They begin to ask why and how moisture moves in the air and when conditions are just right for rain or snow.

STUDENT EXPERIENCES WITH DATA ANALYSIS AND MODELING

In GLOBE Weather, science and engineering practices provide the means by which students advance through the storyline with a particular focus on data analysis and constructing models. They analyze weather data as a way of exploring storm phenomena, including analyzing graphed and mapped data of temperature, precipitation, humidity, and wind. The weather data in this curriculum was collected by GLOBE schools, CoCoRaHS (Community Collaborative Rain, Hail, and Snow) citizen scientists, and the National Oceanic and Atmospheric Administration (NOAA). Students construct models to organize their ideas and share their explanations of weather phenomena with others (see pages 14-15 for more information).



Raindrops (Courtesy: Carlye Calvin, UCAR)

OPTIONS TO EXTEND LEARNING THROUGH GLOBE INVESTIGATIONS

If you choose, we encourage you to have your students collect their own weather data using resources from the GLOBE Program or search for and analyze data collected by other students as a part of the GLOBE Program. This can allow students to conduct their own science investigations and make connections with students around the world. You will need to add time to the unit if you decide to do these optional GLOBE investigations (see pages 12-13 for more information).

WHAT YOU'LL FIND IN GLOBE WEATHER

With five weeks of instruction (approximately 25, 50-minute class periods), GLOBE Weather begins with an Anchor lesson and continues with three guided-inquiry Learning Sequences that explore weather phenomena at increasing spatial (local, regional, and global) and temporal (from short-lived to ongoing) scales. The Culminating Task provides an opportunity for students to apply what they have learned with a new, related phenomenon.

- **Anchor:** GLOBE Weather starts with an anchoring phenomenon: an extreme rainfall event that prompts students to question how and why storms happen and allows students to relate the storm profiled to their own experiences with storms.
- **Three Learning Sequences (LS):** Each Learning Sequence is designed to launch students into a modified 5E learning cycle (Engage, Explore, Explain, Elaborate). There are opportunities to evaluate student understanding along the way. At times, students are prompted to return and reconsider phenomena that they learned about before, such as the Anchor, as they figure out new science they can apply to it.
- **Learning Sequence 1:** Students start with an investigation of short-lived, isolated storms, learning how they typically occur in the afternoon, the relationship between isolated storms and air temperature, and what determines whether growing clouds will cause precipitation.
- **Learning Sequence 2:** Students progress to investigations of how air masses collide at fronts, which can cause stormy weather over a larger region and over many days, especially at cold fronts where a cold air mass pushes into a warm air mass.
- **Learning Sequence 3:** Students zoom out to explore how and why storms move around the world due to atmospheric circulation caused by the uneven heating of the Earth.
- **Culminating Task:** Students investigate a winter storm, applying what they have learned through the curriculum based on their investigations of other types of storm phenomena.

See pages 6-11 for a summary of each lesson.

Next Generation Science Standards



PERFORMANCE EXPECTATIONS (PES)

GLOBE Weather is aligned with three PEs. Note that the strike-through text below denotes concepts that are beyond the scope of this unit.

- **MS-ESS2-5:** Collect data to provide evidence for how the motions and complex interactions of air masses result in changes in weather conditions.
- **MS-ESS2-6 (partial):** Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.
- **MS-ESS2-4 (partial):** Develop a model to describe the cycling of water through Earth's systems driven by energy from the Sun and the force of gravity.

DISCIPLINARY CORE IDEAS

GLOBE Weather combines content from five DCIs. Note that the strike-through text below denotes parts of DCIs that are not covered.

- **ESS2.C:** The complex patterns of the changes and the movement of water in the atmosphere, determined by wind, landforms, and ocean temperatures and currents, are major determinants of local weather patterns. (MS-ESS2-5).
- **ESS2.C:** Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land. (MS-ESS2-4).
- **ESS2.C:** Global movement of water and its changes in form are propelled by sunlight and gravity (MS-ESS2-6).
- **ESS2.D:** Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns. (MS-ESS2-6).
- **ESS2.D:** Because these patterns are so complex, weather can only be predicted probabilistically (MS-ESS2-5).

SCIENCE AND ENGINEERING PRACTICES (SEPS)

GLOBE Weather focuses on two SEPs: (1) developing and using models and (2) analyzing and interpreting data. Additionally, students gain experience with asking questions, carrying out investigations, constructing explanations, and obtaining, evaluating, and communicating information.

CROSSCUTTING CONCEPTS (CCCS)

GLOBE Weather includes three CCCs: (1) cause and effect, (2) systems and systems models, and (3) patterns.

Helpful Prior Knowledge

SCIENCE

Your students' prior learning of physical science concepts and water cycling can notably influence the implementation of the GLOBE Weather unit. While GLOBE Weather reiterates disciplinary concepts that are part of MS-ESS2-4 (water cycling), it is helpful for students to have met the performance expectation prior to GLOBE Weather. Parts of physical science Performance Expectations, particularly those related to DCI PS1.A (Structure and Properties of Matter) at the fifth grade and middle school levels, will also be relevant as you teach GLOBE Weather as students will use the understanding of molecules and how air with different properties interact. Additionally, throughout the unit pay attention to concepts that students may be readily using from previous grades.

MS-ESS2-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the Sun and the force of gravity.

- ESS2.C. Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, crystallization, and precipitation.

5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.

- PS1.A. Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects.

3-ESS2-1. Represent data in tables and graphical displays to describe typical weather conditions expected during a particular season.

- ESS2.D. Scientists record patterns of the weather across different times and areas so that they can make predictions about what kind of weather might happen next.

MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

- PS1.A. Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- PS1.A. The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- PS3.A. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material.

MS-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.



- PS1.A. Structure and Properties of Matter: Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) than can be used to identify it.



GEOGRAPHY


Students will explore weather data on maps in GLOBE Weather. At a regional scale, they will investigate weather fronts over the continental United States. At a global scale, they will investigate how temperatures vary with latitude and how storms move around the world. Thus, a basic understanding of maps and map keys is important as well as concepts such as latitude, the poles, the equator, and cardinal directions (North, South, East, West). Students may need support understanding the difference between a map view and a cross-sectional view.




National Geography Standard 1. How to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information.


GLOBE Weather: Lesson-by-lesson

	LESSON AND QUESTION (TIME ESTIMATE)	WHAT STUDENTS DO	WHAT STUDENTS LEARN
ANCHOR	<p>LESSON 1 Lesson 1: An Unexpected Storm</p> <p><i>What do we know about storms?</i></p> <p>(100 MIN.)</p>	<p>Watch a video about an extreme rainfall event and draw a description of what happened during the storm.</p> <p>Recall experiences with different kinds of storms.</p>	<ul style="list-style-type: none"> • Extreme weather events like the Colorado storm impact our lives and communities. • Storms are a part of the water cycle.
	<p>LESSON 2 Lesson 2: Watching the Sky</p> <p><i>What causes storms to form?</i></p> <p>(50 MIN. PLUS TIME FOR SKY WATCHING)</p>	<p>Make weather observations from sunny and stormy day time-lapse videos.</p> <p> Make GLOBE cloud observations.</p>	<ul style="list-style-type: none"> • Water vapor gets into the sky by evaporation. • Water evaporates when it's heated by the Sun. • Clouds form when water condenses.
	<p>LESSON 3 Lesson 3: Temperature Clues</p> <p><i>How does temperature relate to cloud formation?</i></p> <p>(90 MIN.)</p>	<p>Collect air temperature data from different altitudes in the troposphere using the online <i>Virtual Ballooning</i> interactive.</p> <p>Analyze temperature data collected at Westview Middle School, Longmont, CO.</p> <p> Optional: GLOBE temperature data collection and analysis.</p>	<ul style="list-style-type: none"> • Air temperatures are warmer near Earth's surface and colder as you move higher in the troposphere. • During a sunny day, sunlight warms the ground, which heats the air just above the ground. • Clouds typically build in the afternoon once energy from the Sun has warmed the land surface, which has warmed the air above it.
LEARNING SEQUENCE 1: FROM CLOUD TO STORM			

LESSON AND QUESTION (TIME ESTIMATE)	WHAT STUDENTS DO	WHAT STUDENTS LEARN
<p>LESSON 4 Lesson 4: Fuel for Storms</p> <p><i>What is different about a warm, sunny day and a warm, stormy day?</i></p> <p>(80 MIN.)</p>	<p> Compare weather data collected at a GLOBE school from a sunny day and a stormy day.</p> <p>Create and test models of sunny day conditions and stormy day conditions.</p> <p> Extension: Collect relative humidity and precipitation data following GLOBE Protocols to keep track of the weather.</p>	<ul style="list-style-type: none"> For a storm to form, moisture is needed. Water vapor gets into the air from evaporation off the ocean, lakes, rivers, and from moisture in soil. On days with low humidity, there isn't enough moisture for a storm.
<p>LESSON 5 Lesson 5: Air on the Move</p> <p><i>How does air move and change when a storm is forming?</i></p> <p>(100 MIN.)</p>	<p>Experiment with how warm air rises and cooling air sinks using a Mylar balloon and hair dryer.</p> <p>Make a graphic model to explain how an isolated storm forms</p>	<ul style="list-style-type: none"> As air warms, molecules spread apart. Air becomes less dense and moves upward. As the air at Earth's surface is heated from the Sun, it rises. Higher in the atmosphere, the warm air cools and water vapor within it condenses, forming clouds and possibly a small storm called an isolated storm. When air cools, molecules become closer together. Air becomes denser and sinks to the Earth surface. The pattern of rising and sinking air is called convection.
<p>LESSON 6 Lesson 6: Making a Thunderstorm</p> <p><i>Can we identify the best conditions for storms?</i></p> <p>(50 MIN.)</p>	<p>Test what temperature and humidity conditions will lead to a storm using the online <i>Make a Thunderstorm</i> interactive and graphic models developed during Learning Sequence 1.</p>	<ul style="list-style-type: none"> Changes in temperature or relative humidity will affect whether an isolated storm will happen and how big the storm might be. A strong isolated storm is most likely to happen when there are warm temperatures near the ground, much colder temperatures higher up, and high humidity.

LESSON AND QUESTION (TIME ESTIMATE)	WHAT STUDENTS DO	WHAT STUDENTS LEARN
<p>LESSON 7 Lesson 7: A Different Kind of Storm</p> <p><i>What other types of storms cause precipitation?</i></p> <p>(30 MIN.)</p>	<p>Make weather observations from a time-lapse video of a cold front storm.</p> <p>Analyze a weather forecast for a week when a cold front came through a location.</p>	<ul style="list-style-type: none"> A cold front storm lasts longer than an isolated storm, and there is a dramatic change in the temperature and moisture in the air before and after the storm.
<p>LESSON 8 Lesson 8: Weather Before, During, and After a Cold Front</p> <p><i>How is air changing before, during, and after a cold front?</i></p> <p>(50 MIN.)</p>	 <p>Students analyze air temperature, humidity, and wind data collected by a GLOBE school before, during, and after a cold front.</p>	<ul style="list-style-type: none"> The air before a cold front is warmer with higher humidity. During a cold front, temperature drops and it rains. After a cold front, temperatures are cooler and the air is less humid.
<p>LESSON 9 Lesson 9: Storms and Precipitation Along a Front</p> <p><i>What causes precipitation along a cold front?</i></p> <p>(100 MIN.)</p>	<p>Students make observations and draw a model of what happens in a density tank when warm water (simulating a warm air mass) and cold water (simulating a cold air mass) meet to understand what happens at a cold front.</p> <p>Students create a map of temperature and precipitation data and determine the location of the cold and warm air masses and the front between them.</p>	<ul style="list-style-type: none"> When a cold air mass moves into a warm air mass, the warm air is pushed upward. The warm air cools when it is pushed upward, causing water vapor to condense, and precipitation may occur.

LESSON AND QUESTION (TIME ESTIMATE)	WHAT STUDENTS DO	WHAT STUDENTS LEARN
<p>LESSON 10 Lesson 10: Front on the Move</p> <p><i>What causes fronts to move?</i></p> <p>(100 MIN.)</p>	<p> Students explore air pressure and how air moving downward at areas of high pressure spreads outward at the ground level. Analyzing a map of air pressure data in the Midwest, students determine the direction that the front is moving.</p> <p> Analyzing air pressure data from a GLOBE school, students explain how air pressure relates to cold fronts.</p> <p> Extension: Collect barometric pressure data following GLOBE Protocols.</p>	<ul style="list-style-type: none"> • Areas of high pressure are usually behind a cold front, pushing the cold air mass into the warm air mass. • Air pressure is lower where air is rising at the front. • After a cold front, a location may experience high pressure associated with cooler, sinking air that has less moisture.
<p>LESSON 11 Lesson 11: A Closer Look at Low-Pressure Systems</p> <p><i>What could cause a front to stall?</i></p> <p>(75 MIN.)</p>	<p>Re-watch a video of the Boulder, CO flood from 2013.</p> <p>Examine Boulder, CO storm data from September 2013.</p>	<ul style="list-style-type: none"> • Rainfall totals for the Colorado storm were high because it stalled, causing lots of rain to fall in the same place. • The storm didn't move because it was surrounded by areas of high pressure. • The storm was very moist because low pressure was pulling in humidity evaporated from both the Gulf of Mexico and the Pacific Ocean.

LESSON AND QUESTION (TIME ESTIMATE)	WHAT STUDENTS DO	WHAT STUDENTS LEARN
<p>LESSON 12 Lesson 12: Storms on the Move</p> <p><i>How do storms move around the world?</i></p> <p>(50 MIN.)</p>	<p>Students make observations of time-lapse satellite videos that show storm movement.</p>	<ul style="list-style-type: none"> • There is a predictable pattern of storm movement that correlates with latitude. • In North America and in other midlatitude areas, storms generally move from west to east.
<p>LESSON 13 Lesson 13: Heating Up</p> <p><i>Why is it hotter at the equator than other places on Earth?</i></p> <p>(90 MIN.)</p>	<p> Students explore why it's hotter near the equator than near the poles by interpreting GLOBE temperature data from different latitudes.</p>	<ul style="list-style-type: none"> • Incoming sunlight hits the equator directly, concentrating it in a smaller area than at higher latitudes. • More-concentrated solar radiation causes higher air temperatures near the equator than at higher latitudes.
<p>LESSON 14 Lesson 14: Air Movement in the Tropics</p> <p><i>How and why does air move in the tropics?</i></p> <p>(90 MIN.)</p>	<p>Students use a model to investigate how air moves in large-scale convection from the equator to 30° north and south of the equator. They apply what they learned about small-scale convection to a larger scale to understand where clouds are likely to form and make a model of global convection.</p>	<ul style="list-style-type: none"> • Convection happens on a large scale as warm air rises at the equator, cools, and then sinks at 30°N and 30°S. • There is low pressure at the equator because warm air is rising. • Because air is rising, cloud formation is common at the equator. • There is high pressure at 30°N and 30°S where air is sinking. • Because air is sinking, clear skies are common at 30°N and 30°S. • The rising and sinking air causes air at the Earth's surface in the tropics to move towards the equator.

LESSON AND QUESTION (TIME ESTIMATE)	WHAT STUDENTS DO	WHAT STUDENTS LEARN
<p>LESSON 15 Lesson 15: A Curveball</p> <p><i>When air and storms move, why do they curve?</i></p> <p>(55 MIN.)</p>	<p>Students find evidence that their convection model doesn't explain the pattern by which storms move that they observed in Lesson 12. They read about the Coriolis effect and use a simple model to simulate how Earth's rotation changes the direction of prevailing winds in the tropics.</p>	<ul style="list-style-type: none"> While we'd expect air to move directly towards the equator in the tropics, it actually is curved due to Earth's rotation so that, in the northern hemisphere, tropical air moves from northeast to southwest rather than north to south. In the midlatitudes, air moves mostly west to east due to Earth's rotation.
<p>CULMINATING TASK: Challenge 1</p> <p>Culminating Task: Challenge 1, California Storm</p> <p>(50 MIN.)</p>	<p>Students use what they have learned in GLOBE Weather to explain precipitation patterns and the direction of movement for a winter storm that arrived on the U.S. West Coast on February 21, 2017.</p>	<ul style="list-style-type: none"> Because air temperature decreases with altitude in the troposphere (LS1) the storm could bring snow to high elevations and rain to low elevations in the Sierra Nevada. The storm's moisture most likely comes from evaporation off the Pacific Ocean (LS1). Because storms generally move from west to east in the midlatitudes, due to prevailing winds (LS3), this storm is heading across the U.S.
<p>CULMINATING TASK: Challenge 2</p> <p>Culminating Task: Challenge 2, Where's the Snow?</p> <p>(50 MIN.)</p>	<p>Students analyze maps of snowfall and humidity data in the Rocky Mountains and Southwest for February 23, 2017.</p>	<ul style="list-style-type: none"> Snow fell near the area of low pressure on the northern end of the cold front (LS2). The humidity was low at the southern end of the cold front, which explains why there was no precipitation (LS1).
<p>CULMINATING TASK: Challenge 3</p> <p>Culminating Task: Challenge 3, We're Warning You</p> <p>(50 MIN.)</p>	<p>Will there be a snow day? Students predict which Midwest locations are likely to get enough snow from the winter storm that they will need to close for the day.</p>	<ul style="list-style-type: none"> Predicting where the heaviest snow will fall on February 24 takes into account where it snowed along the front on February 23 (LS2). The forecast, weather watches and warnings, and whether the community is prepared to deal with snow and ice will determine school closures.

Connection with the GLOBE Program

Major funding for the GLOBE Program and GLOBE Weather comes from the National Aeronautics and Space Administration (NASA). The purpose of GLOBE Weather is 1) to produce resource to meet a national need for K-12 science and 2) to introduce teachers and students to the GLOBE Program. A recommendation of a board of advisors during a review of the GLOBE Program in June 2016 stated the following, which led to the development of GLOBE Weather:

“At this moment, U.S. STEM education is under significant pressure to change: new standards such as the Next Generation Science Standards, Common Core, and state-led initiatives increase the visibility and emphasis on inquiry science, Earth and geosciences, and citizen science in K-12 classrooms across the 50 states and other U.S. jurisdictions. GLOBE could play a vital role in these changes ... The GIO [GLOBE Implementation Office] should consider strategies for new initiatives that will increase the use and impact of GLOBE in the U.S. ... to develop and pilot innovative materials for instruction and professional development.”



Making cloud observations using the GLOBE Cloud Protocol (Courtesy: Susan Oltman)

Teachers and students can be introduced to the GLOBE Program through the resources (i.e., science protocols and science data) that have been developed over the 20+ years of the program and are embedded into the unit. GLOBE Weather provides avenues and opportunities for teachers interested in this new way of teaching weather, driven by performance expectations in the Next Generation Science Standards (NGSS Lead States, 2013).

COLLECTING WEATHER DATA USING GLOBE PROTOCOLS

In the unit itself there are implicit opportunities for students to use GLOBE science protocols (i.e., air temperature, surface temperature, clouds, and precipitation) to collect environmental data that can be used to make sense of fundamental concepts (e.g., how solar radiation affects the temperature of Earth’s surface and the air near the ground, how the types of clouds can indicate the type of weather). Using GLOBE protocols will provide opportunities for students to collect authentic data from their local environment, enhancing understanding of concepts related to clouds and air temperature patterns, while encouraging the use of instruments to collect surface and air temperature. This directly aligns with the *Planning and Carrying Out Investigations* Science and Engineering Practices from NGSS.

Science protocols related to the GLOBE Weather curriculum can be accessed in the Atmosphere section of the [GLOBE Program website](http://globe.gov/do-globe/globe-teachers-guide/atmosphere) (globe.gov/do-globe/globe-teachers-guide/atmosphere)

ANALYZING GLOBE WEATHER DATA

Explorations of GLOBE data will lead to a more sophisticated understanding of “how the motions and complex interactions of air masses result in changes in weather conditions” and how to “develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates” (from NGSS Performance Expectations MS-ESS2-5 and MS-ESS2-6). By engaging students directly with the GLOBE Weather materials, teachers use GLOBE resources in their classrooms, benefitting learners.

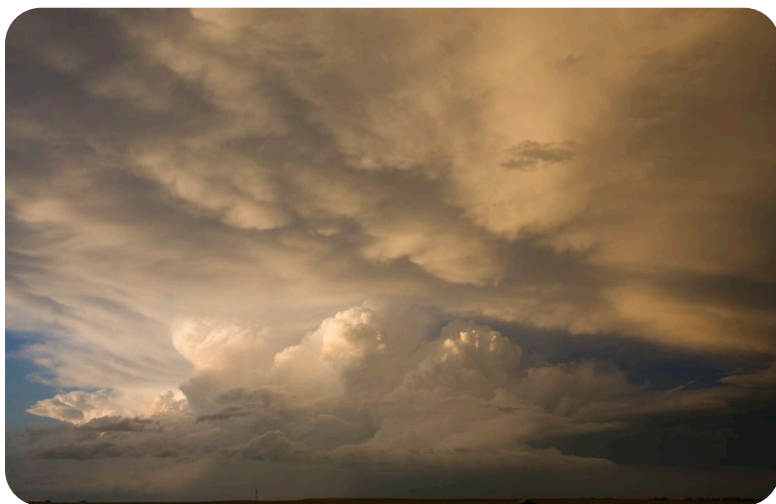
STUDENT RESEARCH PROJECTS

There are also explicit connections for teachers to provide students with more opportunities to conduct investigations. For each learning sequence, we have developed GLOBE Connections that include ideas for using the lessons as a jumping-off point for student research and environmental explorations that use GLOBE protocols, use the GLOBE Visualization Tool, or connect with GLOBE schools from around the world. GLOBE Connections are available on the [GLOBE Weather website](http://globeweathercurriculum.org) (globeweathercurriculum.org).

- In Learning Sequence 1 (From Cloud to Storm), the GLOBE Connection *From Observation to Investigation* has students using their observations and data collected using science protocols to form testable questions for independent or small-group investigations.
- In Learning Sequence 2 (A Front Headed Your Way), students analyze GLOBE data from Freedom High School in Virginia to better understand the movement of a cold front and its associated storms. In the GLOBE Connection *Finding Freedom*, students use the GLOBE Visualization Tool to find the data from Freedom High School and then use the tool to look for other patterns in temperature, humidity, and pressure data that could indicate a cold front in a different part of the United States.
- In Learning Sequence 3 (Worldwide Weather), the GLOBE Connection *GLOBE Schools around the World* introduces students to the international community that makes GLOBE unique. Students are provided with the opportunity to interact with students in GLOBE schools to discuss the question: “Are there regular patterns of storm movement in other parts of the world?”



Students measuring surface temperature using an IR thermometer (Courtesy: Susan Oltman)



Thunderstorms (Courtesy: Carlye Calvin)

These investigations could be part of students' research projects for local science fairs or for submission to the regional [GLOBE Student Research Symposium](http://globe.gov/web/united-states-of-america/home/student-research-symposia) (http://globe.gov/web/united-states-of-america/home/student-research-symposia), the annual GLOBE International Virtual Science Symposium (IVSS) (GLOBE, 2019), or published in the student research repository on the GLOBE website. For the IVSS, students are also encouraged to look at ways to improve their local environments.

As described above, there are many ways for teachers and students to become more involved with the GLOBE Program and at the same time improve their instruction and student learning at the middle school level. The program makes a positive difference in people's lives and benefits the environment.

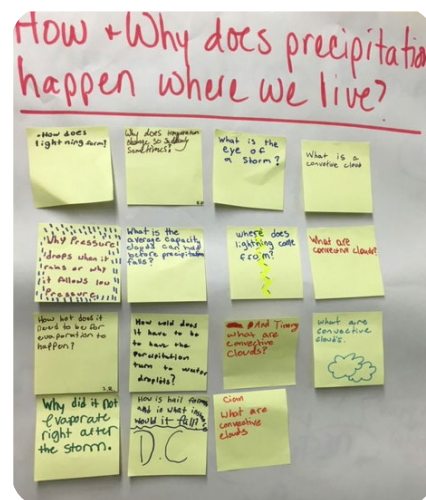
GLOBE Weather Instructional Routines

Throughout the GLOBE Weather unit, you'll notice a few instructional routines used to support NGSS-based science instruction. These routines underpin much of the sensemaking work your students will engage in as they ask questions about and investigate phenomena to figure something out.

THE DRIVING QUESTION BOARD

As part of GLOBE Weather's storyline approach, students articulate questions to define what they need to learn about storms and weather. They document their questions on a Driving Question Board, a tool to generate, keep track of, and revisit student questions related to weather phenomena that students are exploring. The Driving Question Board is a visual representation of the questions generated by the class and is displayed in the classroom during the unit. A Driving Question Board can be constructed with sticky notes or sentence strips, written on whiteboards, or made with shared software applications.

The Driving Question Board is introduced at the beginning of the unit and then revisited periodically. It serves as a record of students' curiosities about phenomena and a way of documenting the progress that they make in understanding the phenomena under study. It is important that students understand there will be more questions on the Driving Question Board than can be answered during the unit.



Example of a GLOBE Weather Driving Question Board (Courtesy: Denise Magrini)

To prepare a paper version of the Driving Question Board:

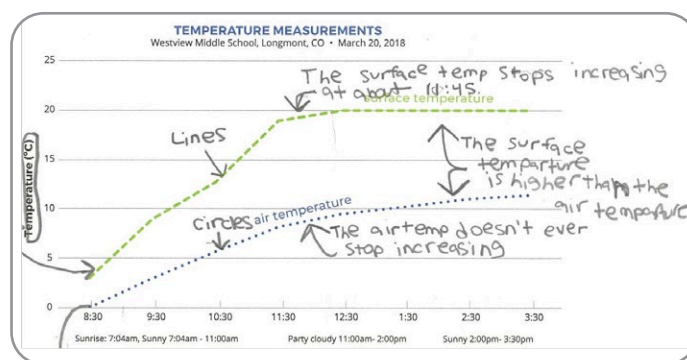
- Write a question on a sheet of poster board or chart paper (see the sample questions in the table on page 16).
- Make a space in the classroom for the Driving Question Board that is easily accessible to students.
- Provide sticky notes and markers that students will use to document their questions.

ANALYZING WEATHER DATA

The Identify and Interpret (I2) Sensemaking Strategy, developed by BSCS, is a way to help students who need support with interpreting graphed data. In GLOBE Weather, the I2 Sensemaking Strategy is embedded within data analysis activity sheets to help students make connections between graphical weather data and their ideas about the science of weather.

The I² Sensemaking Strategy makes sense of graphed data by breaking it down into smaller parts.

- Students make observations of the data. They draw an arrow to each observation and then write a What I See statement to describe it.
- Students write a What it Means statement for each WIS statement. Often, a "What it Means" statement could be more accurately called "What I Think it Means." Encourage students to write these statements to reflect what they think the data is showing, even if they are not completely certain.
- Students create a caption for the graph that summarizes the information and document what they have learned.



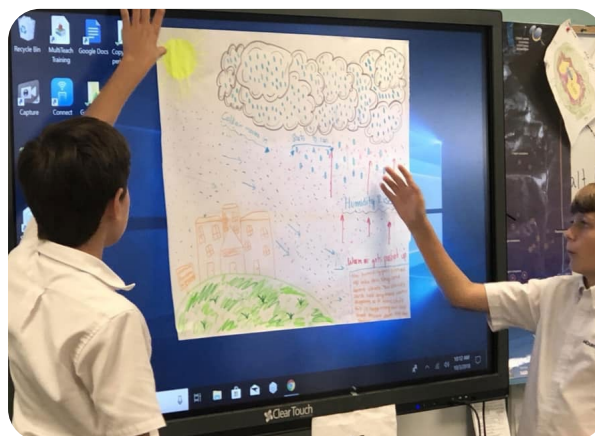
Example of a student's data analysis.

When you first use this strategy, model it for students by completing an I² Sensemaking Strategy on a graph in front of the class while articulating your thought process. Students may need support to understand what they should be looking for on a graph. Help students hone their observations so that they focus on the parts of the data that can help them answer the question they are investigating.

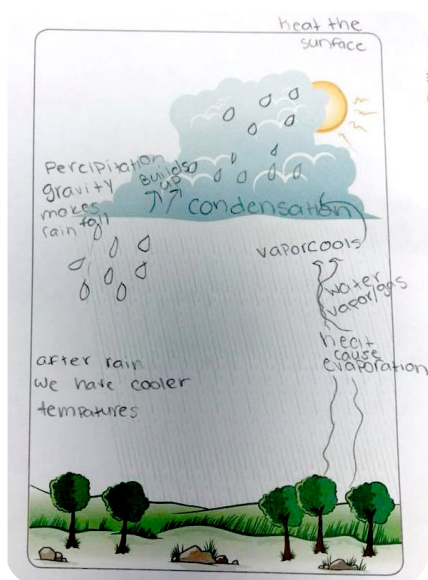
Student-developed Models

A model is an abstract representation of a phenomenon that is used as a tool to explain how or why something in the world works the way it does (McNeill, Katsh-Singer, & Pelletier, 2015; National Research Council, 2013). Scientific models are sensemaking tools that help us to predict and explain the world, while engineering models are used for analyzing, testing, and designing solutions (Passmore, Schwarz, & Mankowski, 2017). In general, models can be represented as diagrams, 3-D objects, mathematical representations, analogies, or computer simulations (National Research Council, 2013).

Developing models is the central activity in GLOBE Weather. Students build conceptual understanding of science by creating and revising models to explain weather phenomena. In GLOBE Weather, students develop models to support their own sensemaking and to help them visually articulate their ideas about atmospheric processes. The models that students develop throughout the unit can be used to track learning progress over time. Below are descriptions of the three types of models that students develop in GLOBE Weather:



Students work together to build consensus models throughout GLOBE Weather. (Courtesy: Susan Oltman)



Example of a student's working model from GLOBE Weather. (Courtesy: Susan Oltman)

- **Working Models:** In each Learning Sequence, students develop Working Models to explain aspects of the phenomenon under investigation. Working Models are a place where students can represent their initial thinking, new ideas, or revised ideas in a low-stakes environment. Working Models can be developed individually or in small groups and then used as a way to share ideas with the class. Working Models are like pieces of the larger puzzle that are put together when the class creates a Consensus Model.
- **Model Ideas and Model Idea Tracker:** Periodically within the unit, students take stock of new Model Ideas—rules that govern how weather works, which students figure out through investigation. The Model Ideas the whole class agrees upon are documented in the class Model Idea Tracker, a piece of chart paper kept in a space in the classroom that students can easily reference.
- **Consensus Models:** In each learning sequence, the class collectively develops a Consensus Model drawing from the Model Ideas in the Model Idea Tracker and the Working Models students have developed to record their own explanation of the learning sequence phenomenon. The Consensus Model is a visual representation that the class agrees will help them explain the learning sequence phenomenon. Students have opportunities to test each Consensus Model, identify its limitations, and add new ideas to it.

The models that students develop are helpful tools for explaining what's happening in the system; however, like all models, they will be imperfect in that they will simplify aspects of atmospheric science. The atmosphere is more complex and chaotic than students will represent in their models, yet student-produced models will represent the primary factors that affect weather, such as changes in temperature and moisture.

HOW PHENOMENA RELATE TO STUDENT QUESTIONS AND SAMPLE MODEL IDEAS FOR EACH GLOBE WEATHER LEARNING SEQUENCE

	LEARNING SEQUENCE 1: FROM CLOUD TO STORM	LEARNING SEQUENCE 2: A FRONT HEADED YOUR WAY	LEARNING SEQUENCE 3: WORLDWIDE WEATHER
Investigative Phenomenon	Clouds can grow during a day and turn into an isolated storm.	Storms forms where different air masses are in contact at fronts. At a cold front, a cold air mass is pushing into a warm air mass.	Precipitation moves from east to west near the equator.
Student Question	<i>What causes an isolated storm?</i>	<i>What other types of storms cause precipitation?</i>	<i>Why do storms move in predictable patterns around the world?</i>
Sample Model Ideas	<ul style="list-style-type: none"> Evaporation of water from Earth's surface is important for clouds/storms to form. Evaporation happens because of heating of the surface from sunlight. Clouds form when water condenses. The surface is warmer than the air above it. The air near the ground is warmer than air near where clouds form. Rising temperature and humidity are good conditions for an isolated storm. Rising temperature and low humidity are not good conditions for an isolated storm. A source of moisture is important to get water into the atmosphere for storms. Warm air rises and cooler air sinks. Warm air can hold more water vapor than cool air. 	<ul style="list-style-type: none"> When cold air meets warm air, the cold air goes below the warm air. The warm air goes up into the atmosphere. Air masses can have different temperatures and amounts of moisture. If a warm, moist air mass is pushed upward, some water vapor will condense into clouds, which can lead to precipitation. An area of high pressure is usually behind a cold front. An area of low pressure is typically at the front/northern end of a cold front (in the northern hemisphere). After a cold front, a location may experience high pressure associated with cooler, sinking air that has less moisture. Just before and during the storm, an area may experience low pressure, which is associated with warm, rising air and precipitation. Air moves from high to low pressure. <p>Colorado 2013 storm-specific model ideas:</p> <ul style="list-style-type: none"> Three areas of high pressure trapped the front and it stalled. The low pressure wasn't moving either and kept pulling in moisture from the Gulf of Mexico and the Pacific Ocean. 	<ul style="list-style-type: none"> As warm air rises at the equator, it creates an area of low pressure. Sunlight (solar radiation) is more concentrated at the equator because incoming sunlight shines directly on the equator, concentrating it in a smaller area. Sunlight (solar radiation) is more spread out toward the poles because incoming sunlight hits the surface at an angle, spreading the light out over a larger area. The amount of concentrated solar radiation influences air temperatures; more-concentrated solar radiation causes higher air temperatures, and solar radiation that's more spread out causes cooler air temperatures. Larger pockets of warm air rise near the equator, and pockets of cool air sink at 30°N and 30°S. Cooler air moves along the surface of Earth toward the area of low pressure to replace the rising warm air. Horizontal movement of air along the surface of Earth is wind, which causes precipitation to move.

Supplies You'll Need

Below is an overview of the supplies that you will need to implement GLOBE Weather in your classroom. A detailed supply list that includes quantities is provided with the instructions for each lesson.

TECHNOLOGY

- Weather videos streamed online and projected for the class (Video URLs are in lesson instructions.)
- Computers or tablets for students use
- Tablets or smartphones (optional)
- *UCAR Field Guide to Clouds* app (optional)
- *GLOBE Observer* mobile app on tablets or smartphones (optional)

SUPPLIES FOR THE DRIVING QUESTION BOARD, MODEL IDEA TRACKER, AND CONSENSUS MODELS

- Chart paper
- Sticky notes
- Markers

HANDOUTS

- Student Activity Sheets for each lesson
- Assessments for each Learning Sequence
- GLOBE Weather Final Assessment

HANDS-ON ACTIVITY AND DEMONSTRATION SUPPLIES

- Latex balloons
- Lentils
- Markers
- Colored pencils
- Cloud identification charts or apps
- 100-watt incandescent bulb and lamp (e.g., clamp lamp)
- Clear plastic soda bottles
- Thermometers
- Funnel
- Sand or soil
- Water
- Rubber stoppers
- Mylar balloon filled with helium
- Hairdryer
- Drinking straw

- Density tank with divider and petroleum jelly
- Electric kettle or other means of heating water
- Ice cubes
- Red and blue food coloring
- Inflatable globe
- Clipboards
- Rulers
- Flashlights
- Graph paper
- Clear plastic tub
- Pipettes
- Sturdy cups, such as ceramic mugs
- Temperature and latitude cards (printed from Learning Sequence 3)
- Tablets or smartphone for taking photos, time-lapse videos, and slow-motion videos (optional)

GLOBE PROTOCOLS

(Note: All are optional extensions except for the cloud protocol.)

- Cloud
 - Cloud and contrail chart
- Air Temperature
 - Min/Max thermometer
 - Calibration thermometer
 - Instrument shelter
- Surface Temperature
 - Infrared thermometer
- Relative Humidity
 - Digital hygrometer or sling psychrometer
- Barometric Pressure
 - Aneroid barometer
 - Altimeter
- Precipitation
 - Rain gauge

[Details about specific equipment needed for GLOBE Protocols](https://www.globe.gov/do-globe/resources/globe-equipment/atmosphere)
(<https://www.globe.gov/do-globe/resources/globe-equipment/atmosphere>)

Navigating the GLOBE Weather Curriculum

Icons within the teacher instructions highlight features of the curriculum, opportunities to deepen student understanding, literacy connections, assessments, and how GLOBE Weather aligns with the Next Generation Science Standards (NGSS). When you see one of these icons, consider what support your students might need and how you can modify instruction to meet those needs.

TEACHER ICONS



Disciplinary Core Ideas: highlights places where you elicit student understanding of core ideas or specify which core idea students are figuring out. Because many activities focus on developing core ideas, this icon is used to highlight core ideas that may need additional attention.



Crosscutting Concepts: highlights the specific concept students are working on and provides additional instructional guidance.



Scientific and Engineering Practices: calls out the specific practice students are engaged with and provides additional guidance on how to facilitate student participation in that practice.



Storyline Link: at the start, middle, and end of each lesson, highlights how to guide students so they experience the unit as a coherent storyline in which each activity has a purpose and is connected to what has gone before and what is coming next.



NGSS Sensemaking: describes the three-dimensional sensemaking students engage with and specifies which practices students engage with to figure out specific core ideas and crosscutting concepts.



Home Learning: provides suggestions for possible home learning assignments.



Literacy Connection: highlights activities that support literacy, such as reading expository text.



GLOBE Connection: indicates times when students collect or analyze GLOBE data.



Dig Deeper: notes suggestion for how to have students explore a topic in more depth if time allows.



Assessment: indicates opportunities to assess student understanding throughout the curriculum.

STUDENT ICONS

The following icons are used on the Student Activity Sheets and indicate the type of activity the students are working on.



What I See (WIS)



What It Means (WIM)



Download File/Application



Play a Video



Work Alone



Work in a Group



Stop and Think



Stop and Do

GLOBE Weather Assessment Resources

EMBEDDED PRE-ASSESSMENT

Lesson 1 of GLOBE Weather provides two opportunities for embedded pre-assessment that can illuminate student thinking and prior knowledge about the connection between the water cycle and weather. In Lesson 1, students are prompted to think, write, and draw to explain what they know about the water cycle, how storms form, and what happened in the Colorado storm example.

In their written answers, look for:

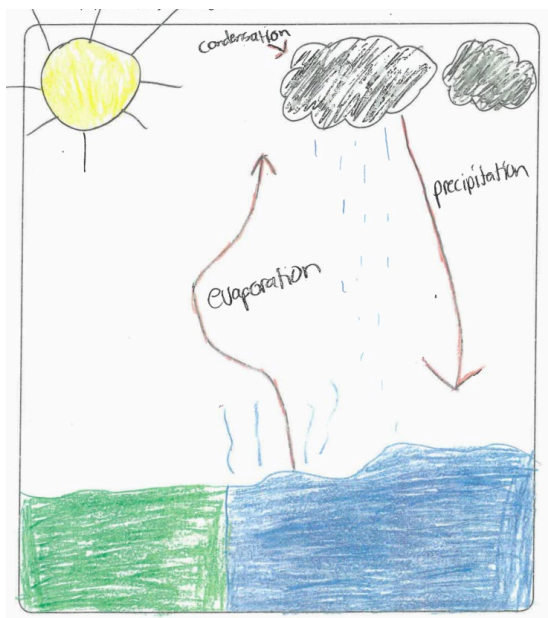
- words and scientific terms they use (e.g., evaporation, precipitation, and condensation) or expression of those ideas without using the terms.
- whether their story focuses mostly on water moving places or whether they also include sunlight, heat, temperature, or other references to energy.

In their drawing, look for:

- the processes students include in their diagrams (e.g., evaporation, condensation, precipitation).
- whether they represent water molecules or represent water on a larger scale.
- whether they include sunlight, heat, or energy as a mechanism for moving water around.

FORMATIVE ASSESSMENT

Each lesson includes a variety of opportunities for formative assessment that correspond to particular parts of student activity sheets and classroom discussions about the models that students are developing and the evidence to support the models. Formative assessment within each learning sequence includes the guiding question for the lesson and descriptions of opportunities to formatively assess students tied to the teacher instructions with exit ticket suggestions (see assessment pages 2-6).



Sample of Lesson 1 pre-assessment student drawing

LEARNING SEQUENCE SUMMATIVE ASSESSMENTS

Each learning sequence has a corresponding summative assessment. The items are open response and prompt students to use their knowledge of disciplinary core ideas and crosscutting concepts and engage in science practices (data analysis and modeling). Interpretive answer keys allow you to make sense of student learning and identify productive thinking and incomplete or inaccurate ideas.

FINAL ASSESSMENT

The final assessment is a ten item open response test that targets fundamental science ideas learned in the unit as well as the NGSS science practices of data analysis and interpretation and modeling. The assessment also prompts students to share what they know about the NGSS crosscutting concepts of patterns and cause and effect. The final assessment should be administered following the culminating task.

References

Bybee, R.W., et al. (2006) [The BSCS 5E Instructional Model: Origins and Effectiveness](#), a Report PDF Prepared for the Institute of Science Education, National Institutes of Health
(<https://bscs.org/reports/the-bscs-5e-instructional-model-origins-and-effectiveness/>)

GLOBE (2019) [GLOBE International Virtual Science Symposium](#)
(<http://globe.gov/web/united-states-of-america/home/student-research-symposia>)

McNeill, K. L., Katsh-Singer, R., & Pelletier, P. (2015). Assessing science practices: Moving your class along a continuum. *Science Scope*, 39(4), 21-28.

National Research Council. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Passmore, C., Schwarz, C., & Mankowski, J. (2017). Developing and Using Models. In C. Schwarz, C. Passmore, & B. Reiser (Eds.), *Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices*. Arlington, VA: NSTA Press.



Umbrellas (Courtesy: Carlye Calvin)



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TEACHER GUIDE

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ANCHOR



THE GLOBE PROGRAM

An Unexpected Storm

What do we know about storms?



The Anchoring Phenomenon for the unit is a storm in Colorado that caused widespread flooding in September of 2013. Because an unusually large amount of precipitation fell, it was called a 1,000-year storm (meaning that the odds of a storm like it happening in the area are one in a thousand). Students brainstorm what they already know about conditions that could have caused the storm and then broaden beyond the Colorado storm to consider other types of storms. Broadening beyond the Colorado storm gives students the opportunity to share what they already know about storms they've experienced and can serve as a bridge between the science they are about to learn and their experiences in their own communities. Students work together to generate a set of questions to investigate in this unit to better understand the Colorado storm and other kinds of storms as the unit driving question—What causes different kinds of storms?—is introduced.

SCIENCE IDEAS

Weather impacts our lives and the communities where we live. There are many factors that have an impact on how storms form and the amount of precipitation they cause.




An Unexpected Storm

What do we know about storms?

ANCHOR

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(100 minutes)	
<p>Introduce the Anchoring Phenomenon Students watch a video profiling a storm with extreme precipitation and its impact on a community.</p>	<p>Lesson 1: Student Activity Sheet </p> <p>Colorado flood video/images</p>
<p>Eliciting Prior Knowledge and Experiences Students share their initial ideas about what caused the heavy precipitation and where all the water came from. The discussion broadens to students' experiences of storms and precipitation, particularly in their community.</p>	
<p>Modeling Storm Formation Students illustrate what they know about storm formation using a diagrammatic model. They compare their representations to those of their classmates looking for similarities and differences. Students wonder about parts of their models that are different or incomplete.</p>	
<p>Driving Question Board Students are introduced to the driving question: "What causes different kinds of storms?" Students generate their own questions related to the driving question. The questions are recorded publicly and are used as one way to create a shared mission to figure out more about storms and precipitation.</p>	<p>Whiteboard, smart board, or chart paper and markers (to make the Driving Question Board)</p> <p>Sticky notes (or comparable way to post student questions)</p>



AN UNEXPECTED STORM

What do we know about storms?

ANCHOR



NGSS Sensemaking

The Anchor lesson is sequenced to encourage students to draw on their prior experiences and knowledge of storms and water cycling. Prior to this unit, students should have studied water cycling (MS-ESS2-4). Students use their experiences and knowledge to start explaining causes of storms. At this point in the lesson, it is not expected that students will have correct or fully developed ideas about the Anchoring Phenomenon (the Colorado storm). Through the process of sharing their initial ideas and broadening to related phenomena, students recognize that they know some “stuff” about storms but that they also have questions about the Colorado storm and storms more generally. Uncertainty about what is happening in a storm motivates students to ask questions. The class develops a joint mission to know more about what causes storms to form, why some storms have exceptional amounts of precipitation like the Colorado storm, and what kinds of storms and global circulation patterns typically affect their community.

NGSS DIMENSIONS (GRADES 6-8)

- Water continually cycles among land, ocean, and atmosphere via evaporation, condensation, and precipitation. Global movement of water and its changes are propelled by sunlight.
- Ask questions that can be investigated within the scope of the classroom and outdoor environment.

Teacher Procedures

Introduce the Anchoring Phenomenon



1. **Introduce the new unit on weather.** Students should have some prior understanding of water cycling and its role in weather formation. This lesson will build upon that understanding. (It may be helpful to review the water cycle together using a diagram your students are familiar with.) Your introduction should take into account where your students are in their learning about water cycling and weather.

An example introduction could be:

“Severe weather can put people’s lives and property at risk. If we can predict when severe weather is likely to happen, we can help people be better prepared when it happens. In this unit, we are going to explore where, when, and why storms form and how we can predict the ways in which they might impact communities, especially by bringing heavy rain or snow.”

2. **Watch the video of the Colorado storm.** Before showing the video, ask students to think about the different ways communities are affected by precipitation or a lack of precipitation. Help students identify a few ways our communities are uniquely dependent on precipitation. Then show the video.



CASE STUDY: COLORADO FLOODS

In September 2013, a storm stalled over the region around Boulder, Colorado bringing a weeklong deluge of rain, resulting in dangerous floods.

Video: [How the City’s Resilience Strategy Saved It](#)

(<http://scied.ucar.edu/video/boulder-colorado-flood-how-citys-resilience-strategy-saved-it>)

Before/After Images: [What Flooding Looked Like in Boulder](#)

(<https://scied.ucar.edu/interactive/boulder-floods>)

The video is 6 minutes, 48 seconds in length and provides a case study. For this lesson, focus on the first part of the video (up to 2:08). If you would like to show more of the video, the following break down and time codes are provided:

0:00-2:08—Introduction to the 2013 Colorado floods and past floods in this same area. Some effects are shown.

2:09-4:11—Engineering considerations related to managing future floods based on past experiences are addressed.

4:12—End of video on the 2013 flood and community resilience.

6:13—A cause is mentioned.

LESSON
1
STEP 1

3. **Discuss students' ideas about the causes of the storm.** Direct students to the *Lesson 1: Student Activity Sheet*. After watching the video, have students write their ideas in *Lesson 1: Step 1*. Allow students to share what they heard about causes of the precipitation in the video (e.g., a very slow-moving storm, an unusual amount of water vapor in the air) or their own ideas about what caused the heavy precipitation. As students share, wonder aloud: "Is that a cause of the storm or an effect from the storm?"

Suggested prompts for discussion:

- *Where did all the moisture over Colorado come from?*
- *What had to happen to make that moisture turn into rain?*
- *Has our community experienced too much or too little precipitation before?*

Note: Remind students to focus on what factors caused the rainstorm and not the flood.

ELICITING PRIOR KNOWLEDGE AND EXPERIENCES
LESSON
1
STEP 2

1. **Broaden the discussion to other storms and precipitation.** Working in small groups, ask students to share their experiences of storms and precipitation in *Lesson 1: Step 2*. This can include their experiences with storm impacts such as flooding, damage to structures, or loss of power, as well as safety considerations such as avoiding lightning or floods. This is a great opportunity to incorporate any recent or significant local storm experiences that your students might remember into your discussion.
2. **Focus the discussion on water cycling and precipitation.** Students will bring a variety of experiences to the broadening discussion. As students share, elicit what they know about water cycling processes. As students share, record important ideas that students appear to agree upon. These ideas will be helpful leading into the modeling activity next.

Suggested prompts:

- *How do storms begin in the first place?*
 - *What needs to happen so that rain or snow starts to fall?*
 - *Why do some places get heavier precipitation but other places do not?*
 - *Where does all the water come from before it falls as rain or snow?*
3. **Notice if your students have any misconceptions pertaining to a specific part of the water cycle.** For example, a common misconception is that clouds are made of water vapor instead of liquid water. Addressing any misconceptions now will aid your students as they progress through the lessons.


Cause-Effect

Have students focus their ideas on the causes of precipitation. Students may also want to discuss the effect of precipitation on communities. A cause and effect organizer may be useful for structuring this discussion.


The Water Cycle

Elicit what students know about water cycling processes that lead to precipitation (ESS2.C).

MODELING STORM FORMATION



LESSON
1

STEP 3

1. **Prompt students to draw an initial model.** Their model in *Lesson 1: Step 3* should represent the factors they believe led to the unusual amount of precipitation in the area around Boulder, Colorado. Tell students to draw and label as much as they know about how storms form, including when and where, that can help them explain the Colorado storm. If students are not yet familiar with drawing graphic models, summarize the activity by explaining how their illustration is a model because it represents processes that happen on Earth. This type of model development is a consistent feature of GLOBE Weather.

LESSON
1

STEP 4

2. **Compare students' initial models.** Use small groups for students to share and compare their models. Ask students to compare similarities and differences between how each group member represented the storm in *Lesson 1: Step 4*. Then, groups summarize for the class what they noticed and wondered about as they compared their models. At the same time, support the discussion by doing the following:
 - Voice how the models make you wonder and question what's happening in the storm: *"This is really interesting, as we see all these different ideas about how this might work. It makes me think of lots of questions. I'm curious about all the ideas I didn't really think about before."*
 - Point out common features/mechanisms that students were using across models, such as clouds, wind, air, precipitation, and temperature differences. Consider recording these common features in a public space.
3. **Set the class mission.** After students share their models, tell them that more investigation is needed to better understand the cause of storm formation: *"We should try to figure out how all of this works to cause a storm."*

DRIVING QUESTION BOARD



LESSON
1

STEP 5

1. **Orient students to the Driving Question Board.** In a public space—either physical or digital—share the Driving Question Board with students. The Driving Question Board can be a bulletin board, a piece of butcher paper or chart paper posted on the wall, or a piece of paper projected on a document camera. A digital board is possible, but the purpose of the Driving Question Board is to publicly document students' questions. Therefore, the Driving Question Board should be visible to students throughout the unit. This is where the students post their questions and where students return to answer their questions throughout the unit. The Driving Question Board should have the unit driving question written at the top: *"What causes different kinds of storms?"*
2. **Ask students to write and share questions.** Explain to students that by the end of the unit, they should be able to answer the driving question but that they also should have their own questions. Ask students to write their own questions related to the driving question and the Anchoring Phenomenon at the bottom of their activity sheet in *Lesson 1: Step 5*. Then have students share these initial questions in a small group to refine the questions before posting them to the Driving Question Board.
3. **Post students' questions to the Driving Question Board.** Pass out sticky notes (or a comparable method) to groups of students and have them write their questions on the notes. Ask individual students or student groups to share their questions with the class. As student groups share their questions have them post the questions to the Driving Question Board.



Developing a Model

Visual representations, like graphic models and concept maps, are one way to represent important relationships in a system.



Asking Questions

Students generate questions (collaboratively) to explore throughout the unit to better understand the phenomenon of storms and heavy precipitation.



Storyline Link

Brainstorming helpful investigations and data can serve as the bridge for transitioning to data analysis in the next lesson.

(Note: If you choose a digital option, be prepared to project the digital board for the whole class now and also revisit the digital board throughout the unit.)

4. **Organize questions on the Driving Question Board.** As you notice patterns emerge with student questions, help students to organize the questions around similar themes.

5. **Prompt students to brainstorm what data or information they need to answer their questions.** After students share their questions, focus students on: *“What sort of data could we analyze or what sort of investigations could we do in our class to help us answer our questions.”* Ask students to take a moment to think about this, then record their ideas on a piece of chart paper or in a designated area on the Whiteboard and/or near the Driving Question Board (e.g., *“we need videos of storms and clouds, we need weather reports and data, maybe we need to do some experiments with water”*).



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LEARNING SEQUENCE 1

ENGAGE

LESSON
2

WATCHING THE SKY

EXPLORE

LESSON
3

TEMPERATURE CLUES

LESSON
4

FUEL FOR STORMS

EXPLAIN

LESSON
5

AIR ON THE MOVE

ELABORATE

LESSON
6

MAKING A THUNDERSTORM

From Cloud to Storm

What causes an isolated storm?



Precipitation is a regular phenomenon in our lives. Every morning, as the Sun peaks over the horizon, the sunlight we receive begins a chain of events that often leads to cloud formation across the day. If the conditions are just right, the clouds turn into thunderstorms. In this learning sequence, students begin their investigations of storms and precipitation looking closely at small-scale convective storms that happen within an air mass. These small-scale convective storms serve as an investigative phenomenon for this learning sequence. These storms are called “isolated storms” or “afternoon thunderstorms” because they often happen in the afternoon. In this learning sequence, we use the term isolated storms because they do not always happen in the afternoon, and we focus on their formation rather than their location within air masses (since students will learn about air masses in the second learning sequence). Isolated thunderstorms are usually short-lived and small in scale. These storms can cause hazardous conditions, such as lightning and small tornadoes. They also cause precipitation, which can be a welcome respite from summer heat. In this learning sequence, students learn about important factors related to isolated storm formation, such as the temperature differential between the surface and the clouds and the availability of moisture. Students also learn about convection as a lifting mechanism that moves warm, moist air vertically, allowing storm clouds to form.

SCIENCE IDEAS

Sunlight heats Earth’s surface and evaporates water in a location. As surface temperatures rise, so does air temperature. The rising temperatures near the surface coupled with rising relative humidity from evaporating water lead to good conditions for storms to form. Warm air, which can hold more water, rises through the atmosphere. As it cools, the air can no longer hold as much moisture. The cool temperatures lead to condensation and precipitation.

Background Science Content

HOW DO CLOUDS FORM?

Clouds are made of small water droplets or ice crystals depending on the air temperature. These water droplets and ice crystals form from water vapor. The water in the atmosphere can be a solid (ice and snow), a liquid (rain), or a gas (water vapor). These three different phases depend on temperature and pressure. Water vapor gets into air mainly by evaporation of liquid water from the surface of ocean, lakes, and rivers. Air that is cool and under less pressure can evaporate less water vapor than air that is warm and under higher pressure.

Variations in the air temperature and pressure allow clouds to form. For example, as temperature and humidity rise throughout the day, cumulus clouds can build, leading to isolated afternoon storms, the main phenomenon that students explore in this learning sequence. The Earth's surface is heated by sunshine, which then heats the air above it. That warmed air starts to rise because, when warm, it is lighter and less dense than the air around it. As it rises, its pressure and temperature drop resulting in water vapor becoming small water droplets or ice crystals. It's easier for water vapor to condense into water droplets when it has a particle to condense upon. These particles, called condensation nuclei, can be dust, pollen, or air pollution that is suspended in the atmosphere. Eventually, enough water vapor condenses upon condensation nuclei to form a cloud.



- For additional information, visit [The Water Cycle](https://scied.ucar.edu/learning-zone/how-weather-works/water-cycle) (scied.ucar.edu/learning-zone/how-weather-works/water-cycle)

PRESSURE AND TEMPERATURE DECREASE WITH ALTITUDE IN THE TROPOSPHERE, ALLOWING CLOUDS TO FORM.

In the first part of Lesson 3, students explore temperature change between 0-12 km in the atmosphere using the Virtual Ballooning simulation; however, they may see other patterns in the data if they choose to toggle between temperature and pressure or if they get data that goes beyond 12 km.

The troposphere is the lowest layer of the atmosphere found from ground level up to about 10 km (33,000 feet) above sea level on average. We live in the troposphere, and nearly all weather occurs in this lowest layer. Almost all clouds are in the troposphere along with 99% of the water vapor in the atmosphere. The online Virtual Ballooning simulation illustrates how air temperature and pressure change with altitude. This curriculum uses the Virtual Ballooning activity to focus on the troposphere. Weather balloons that carry instruments are one way that scientists explore what's happening higher up in the sky to help them better understand what might be happening where clouds form.

Energy from the Sun that penetrates the Earth system is mostly absorbed by the ground and then released as heat in infrared wavelengths of light. Both air pressure and temperature decrease as you climb higher in the troposphere. Air pressure, a measure of the weight of the molecules above you, decreases with altitude because air molecules higher up in the atmosphere have fewer molecules above them, so less weight. Lower air pressure allows air molecules higher in altitude to move apart from each other, which causes the air temperature to decrease.



For more information, visit:

- [Change in the Atmosphere with Altitude](https://scied.ucar.edu/webweather/weather-ingredients/change-atmosphere-altitude) (https://scied.ucar.edu/webweather/weather-ingredients/change-atmosphere-altitude)
- [Virtual Ballooning to Explore the Atmosphere](https://scied.ucar.edu/virtual-ballooning) (https://scied.ucar.edu/virtual-ballooning)
- [The Troposphere](https://scied.ucar.edu/learning-zone/atmosphere/troposphere) (scied.ucar.edu/learning-zone/atmosphere/troposphere)

THERE ARE MANY TYPES OF CLOUDS.

By observing clouds and identifying cloud types we can learn about the temperature, moisture (humidity), and wind conditions at different heights in the atmosphere, which helps in predicting the weather. Clouds can indicate that moist air is moving upward. This can lead to precipitation. However, many cloud types do not cause precipitation. The GLOBE cloud chart below indicates cloud types and the altitude (low, mid, high) at which they are found. Observations of clouds also help us to know how much sunlight is reaching the ground and how easily heat from the ground and lower atmosphere can escape to space. Clouds play a central role in controlling the exchange of heat in the atmosphere, and changes in clouds over time can have significant climate impacts with some types of clouds trapping heat in the atmosphere and others blocking solar energy from getting to Earth.

Cloud Identification Chart

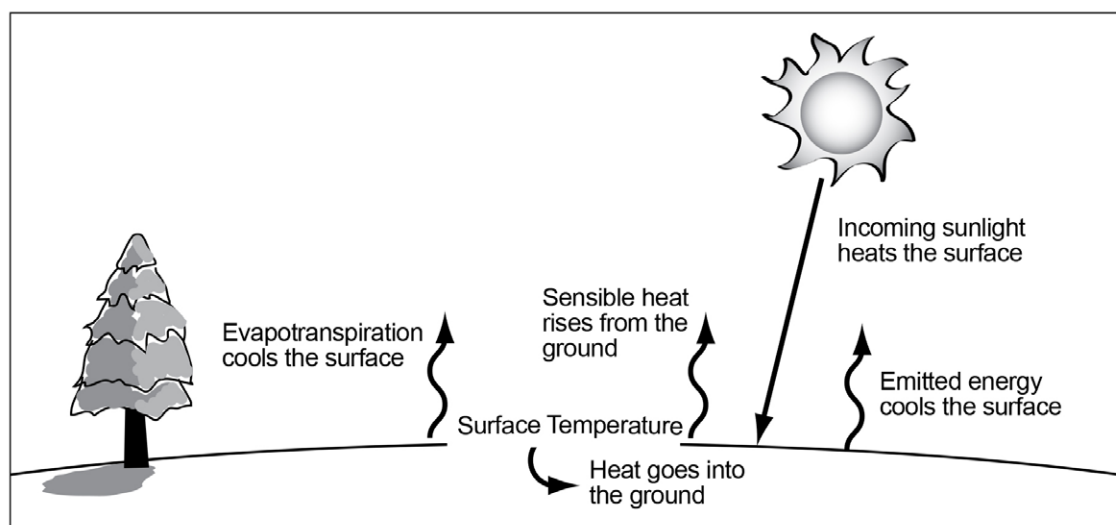


2019

The types of clouds you see in the sky depend on weather conditions in the area. Some clouds form only in fair weather, while others bring rain showers or thunderstorms. Specific cloud types can indicate a trend in the weather. Convective clouds associated with thunderstorms and precipitation include cumulus and cumulonimbus clouds. For example, in middle latitudes, before a cold front, you can observe cirrus clouds and then cumulonimbus clouds as the cold front passes through.

HEAT FROM THE SUN CAUSES CONVECTION IN THE ATMOSPHERE.

Energy from the Sun leads to heating of the Earth's surface and evapotranspiration as shown in the image below. The incoming solar radiation is affected by cloud cover, cloud type, and albedo (reflectance) of the surface of the Earth. Overall, about half of all incoming solar radiation is absorbed by the land surface and oceans. Surfaces that absorb sunlight warm up. The air above the Earth's surface is warmed through sensible heat. In addition, while evaporation is the movement of water to the air from different sources, such as bodies of water, evapotranspiration is the sum of evaporation and transpiration from plants.



Partitioning of the Sun's Energy as Related to the Earth's Surface Temperature. Found in GLOBE Surface Temperature Protocol Reading (Courtesy: GLOBE).

There are many different materials covering the Earth's surface, such as soil, rocks, water, forests, snow, and sand. Materials like these have different ways of dealing with the solar energy that gets to our planet, which affects surface temperature. During the infrared thermometer activity in this learning sequence, students look closer at surface temperatures and whether temperatures vary depending on land cover. The amount of energy reflected by a surface is called albedo. Dark colored surfaces, such as asphalt, concrete, or vegetation have low albedo and reflect very little of the solar energy that gets to them and therefore have higher surface temperatures. In contrast, light-colored surfaces, such as snow, ice, water, and bare soil, reflect almost all of the solar energy that gets to them resulting in lower surface temperatures.



For more information, visit:

- [Surface Temperature Protocol](https://www.globe.gov/documents/348614/7537c1bd-ce82-4279-8cc6-4dbe1f2cc5b5) (https://www.globe.gov/documents/348614/7537c1bd-ce82-4279-8cc6-4dbe1f2cc5b5)
- [The Energy Budget](https://scied.ucar.edu/learning-zone/how-climate-works/energy-budget) (scied.ucar.edu/learning-zone/how-climate-works/energy-budget)

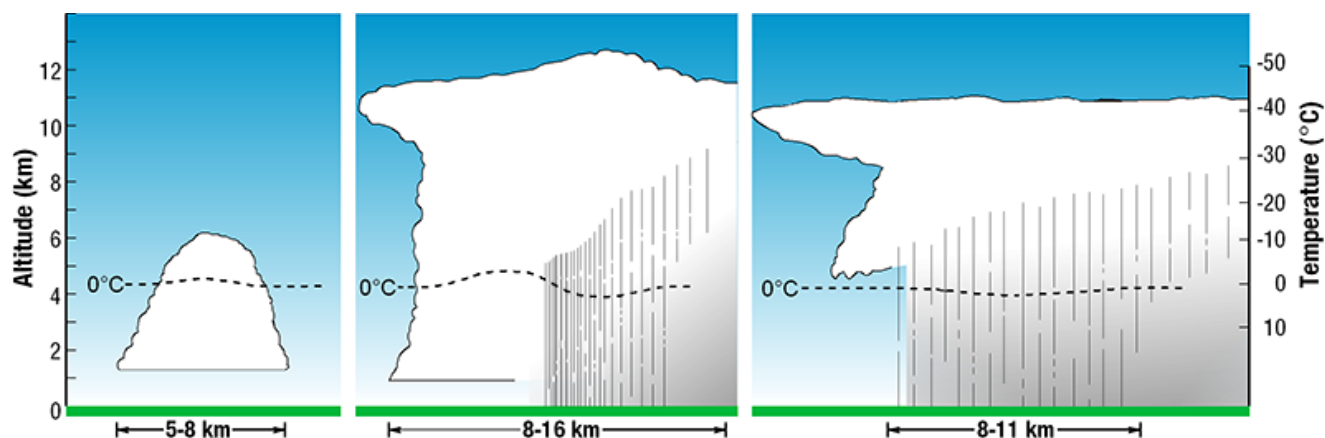
CONVECTION IN THE ATMOSPHERE CAUSES ISOLATED STORMS.

Air near the ground, warmed by the Earth's surface, rises because it is less dense. This air cools and expands as it rises and can cause cumulus clouds to form. When water vapor condenses, heat (latent heat/energy) is released. This energy can help a thunderstorm grow via convection, the transfer of energy and mass in motion in a liquid or a gas. In the atmosphere, convection usually refers to the vertical movement of air. Cold air sinks from the upper levels of the atmosphere.

Convection is the primary mechanism driving cumulus cloud formation. Meteorologists usually use convection to refer to the upward motion as updrafts and the downward motion as downdrafts. Convection forms clouds as heat is transferred in the air as warm air rises to condensation level. Supercell thunderstorms occur when very strong updrafts are balanced by downdrafts, which can allow the storm's cumulonimbus clouds to persist for many hours. The three main stages of thunderstorm development are developing (cumulus) stage, mature stage, and dissipation stage. The developing and mature stages are the focus of the phenomenon that students are investigating in this learning sequence. Updrafts occur in the developing stage, while there are both updrafts and downdrafts in the mature (maximum growth) stage of the thunderstorm.



For more information, visit [How Thunderstorms Form](https://scied.ucar.edu/learning-zone/storms/how-thunderstorms-form) (<https://scied.ucar.edu/learning-zone/storms/how-thunderstorms-form>)



Three Stages of a Thunderstorm (Courtesy: NOAA).

PRECIPITATION DEPENDS ON WATER VAPOR IN THE ATMOSPHERE.

If there is enough moisture (water vapor) in the air, clouds can form and precipitation is possible. Water vapor gets into the air by evaporation, transpiration, and respiration.

Relative humidity (RH) is the percent of water vapor in the air compared to the maximum amount of water vapor that the air can hold. It's measured with a digital hygrometer or a sling psychrometer. When air is saturated with water vapor, the relative humidity is 100%. Because cool air has less energy, water is less likely to evaporate, so it can hold less water vapor than warm air. Warm air has more energy and, thus, has the ability to evaporate more water so it can hold more water. The same amount of water vapor may cause 100% relative humidity in cool weather and only 50% relative humidity in warm weather. In GLOBE Weather, relative humidity is referred to as "humidity."

On a clear, sunny day, the relative humidity is higher in the morning than in the afternoon because cooler morning air is closer to saturation than hot afternoon air with the same amount of water vapor. In contrast, on days with precipitation or significant cloud cover, relative humidity often increases during the day as clouds grow and the temperature is not as warm. Note that the relative humidity in a cloud is 100% as precipitation is falling, but relative humidity at the ground level, where it is typically measured, will often be lower.

Both low and high humidity can be hazardous. Low humidity can lead to dehydration, fatigue, and dry, cracked skin. High humidity can lead to heat strokes and heat exhaustion because sweat does not evaporate off the skin.



For more information, visit [How Weather Works: Humidity](https://scied.ucar.edu/learning-zone/how-weather-works/humidity) (<https://scied.ucar.edu/learning-zone/how-weather-works/humidity>)

COMMON MISCONCEPTIONS:

The following science misconceptions were identified by GLOBE Weather field test teachers. Watch out for them as your students are learning about weather.

MISCONCEPTION	CORRECT EXPLANATION
Air is warmed directly by the Sun.	Energy from the Sun is absorbed by the Earth's surface, which causes the surface temperature to rise. Air that comes in contact with the surface is heated by conduction. Thus, it is the Sun's warming of the Earth's surface that affects air temperatures in the lower troposphere and not the Sun warming the air directly.
Air that is higher in the sky is warmer because it is closer to the Sun.	In the troposphere, air temperature decreases as altitude increases. This is because the troposphere is heated from below (as described in the previous misconception above) and also because at higher altitudes there is less air pressure, which causes air molecules to spread out. With more space between each air molecule, they are less able to retain heat (there are fewer heat transferring collisions between molecules).
Peak air temperature happens when the Sun is highest in the sky.	Even though the Sun is highest in the sky around midday, air temperature continues to rise later in the day because the air above Earth's surface is warmed from the ground up. The air temperature is often warmest a couple hours after the Sun has reached its peak in the sky.
Clouds are made of water vapor.	Liquid water turns into water vapor when it evaporates and rises up into the sky; however, clouds form at the point where the air is cold enough for the water vapor to condense back into liquid water or even frozen water crystals. This condensation happens around small particles called condensation nuclei. Thus, clouds are made of either liquid water droplets and/or frozen ice crystals but not water vapor. Probe students with questions to identify whether they understand the reason that water changes phase within the weather side of the water cycle. For example, water vapor will condense into liquid water when air cools, forming clouds. Help students make connections between the water cycle and the formation of clouds and rain.
Confusion about how air temperature and humidity relate to isolated storms.	On a day with afternoon rain showers, air temperature would likely rise during the day and drop before it rains. As air temperature rises, air molecules are farther apart and humidity increases because the warmer air can hold more water vapor. Humidity would be high during the day leading up to the storm because you need moisture for a storm to form. Students should recognize that air temperature and humidity are important for storm formation.
It only rains when the humidity is 100%.	For the rain to fall, the humidity in the atmosphere, where the clouds have formed, must be 100%. But the relative humidity at the surface can be less. If the air at the surface is very dry, rain that is falling could evaporate before it even hits the ground, which is called virga.


 LESSON 2

WATCHING THE SKY

What causes storms to form?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes, plus time for sky watching)	
<p>Making Observations: Sunny Day / Stormy Day Students brainstorm how observations can help them make sense of weather. Students watch time-lapse videos, which are one way to see what's happening in the sky over time. The time-lapse videos show the sky on a sunny day and a stormy day from sunrise to sunset. As students watch each video, they make visual observations to compare the conditions and movement of clouds in the sky over time.</p>	<p>Lesson 2: Student Activity Sheet </p> <p>Whiteboard, smart board, or chart paper and markers (to make the Driving Question Board and Model Idea Tracker)</p> <p>Sunny day time-lapse video (2 min.)</p> <p>Stormy day time-lapse video (2 min.)</p>
<p>Diagram of a Storm Forming Students go further with the stormy day time-lapse video and model how the storm began, grew, and dissipated. Students draw a model of each of these stages of a storm. Students compare their diagrams to those of their peers.</p>	
<p>Sky Watching Option 1: Cloud Observations Students are encouraged to make observations of clouds over a few days, recording observations in their notebooks or using a data sheet. Students can also make time-lapse videos of clouds and use those videos as evidence of how clouds change over time.</p>	<p>Device with time-lapse capabilities</p> <p>GLOBE Cloud Chart (globe.gov/globecloudchart)</p> <p>Science notebook to record cloud observations</p>
<p>Sky Watching Option 2: GLOBE Cloud Protocol Students are introduced to the GLOBE Cloud Protocol and use the protocol to make observations. Students record their data on GLOBE protocol observation sheets and enter their data into the GLOBE website or via the GLOBE Observer app.</p>	<p>GLOBE Cloud Protocol (globe.gov/do-globe/globe-teachers-guide/atmosphere)</p> <ul style="list-style-type: none"> • Data sheet or GLOBE Observer app • GLOBE cloud chart • Data entry options • UCAR Field Guide to Clouds app (scied.ucar.edu/apps/cloud-guide)



WATCHING THE SKY

What causes storms to form?



NGSS Sensemaking

Students engage in developing initial explanations and diagrammatic models to explain isolated storm formation. During their discussion of the growing thunderstorm, students are expected to use what they know about the water cycle and phase changes of water and the heating of Earth and transfer of energy to help explain the storm. The purpose of this lesson is to elicit students' prior knowledge about water cycle processes and the water cycle's connection to weather. Additionally, the lesson should create a heightened awareness that something interesting is happening on days when there is a thunderstorm compared to a sunny day, and that they need to collect more data and gather additional information to help them explain storms. Cloud observations are one source of data they can collect as they investigate this phenomenon.

PERFORMANCE OUTCOME

Develop a model to describe how clouds form during a stormy day and build until they form a rainstorm.

NGSS DIMENSIONS (GRADES 6-8)

- Water continually cycles among land, ocean, and atmosphere via evaporation, condensation, and precipitation. Global movement of water and its changes are propelled by sunlight.
- Develop a model to describe unobservable mechanisms.
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Identify limitations of models.

Teacher Procedures

Making Observations: Sunny Day / Stormy Day

- Navigate from the previous lesson.** Give students an opportunity to discuss where they left off in the Anchoring Phenomenon (Lesson 1). Remind students of their questions on the Driving Question Board and the need for further investigation of their questions.
- Assess students' prior knowledge about water cycling and phase changes during cloud formation.** In pairs, have students explain to each other how water on the Earth's surface might end up as a cloud in the atmosphere. Students may want to sketch a diagram on scratch paper or in their science notebook to help explain their thinking. Instruct students to focus on anywhere water is changing phase (e.g., from liquid to gas and back to a liquid). After explaining in pairs, hold a whole class share out to assess understanding. Provide direct instruction and vocabulary (e.g., water vapor, condensation) as needed.
- Transition to the importance of making observations of the sky, specifically clouds.** Direct students to the *Lesson 2: Student Activity Sheet*. Have students complete *Lesson 2: Step 1* on the activity sheet with partners or in small groups. Students are prompted to think about the purpose for observing clouds and how observations are beneficial for understanding weather. Allow time for students to share why cloud observations, or other observations of the weather/sky, can be useful.

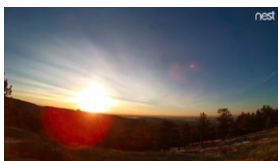
LESSON
2
STEP 1

Suggested prompts for discussion:

- *What can we learn about the weather by observing the sky over time?*
- *What would we see if we watched the sky on a day when a storm was forming?*
- *How could viewing a time-lapse video of the sky help us figure out more about clouds and storms?*

LESSON
2
STEP 2

- Make observations of sunny day and stormy day time-lapse videos.** Introduce students to the time-lapse video context (see below). Play the sunny day time-lapse video. Have students make observations in *Lesson 2: Step 2* of their activity sheets. As students observe, help them identify evidence from the video that indicates time of day. Next, play the stormy day time-lapse video and have students make observations on their activity sheets. Identify indicators for time of day—this is important for establishing that the morning begins clear, clouds appear, and the storm occurs in the afternoon.



SUNNY DAY AND STORMY DAY TIME-LAPSE VIDEOS

These videos were captured on Eagle Ridge above Lyons, Colorado near the Front Range of the Rockies by David Niels as part of his research for the Colorado Climate Center. The sunny day video was filmed on April 6, 2017. The stormy day video was filmed on July 4, 2017. Each video is two minutes in length.

[Sunny Day Video](https://scied.ucar.edu/video/sunny-day-2017-04-06) (https://scied.ucar.edu/video/sunny-day-2017-04-06)

[Stormy Day Video](https://scied.ucar.edu/video/stormy-day-2017-07-04) (https://scied.ucar.edu/video/stormy-day-2017-07-04)



Cause-Effect

As students discuss differences between the two days, elicit their ideas about what is causing the storm to form.

LESSON
2
STEP 2

5. **Have students write their ideas and discuss the guiding question: “Why do you think that the storm formed on one day and not the other?”** (*Lesson 2: Step 2, continued*) Prompt students to generate their initial ideas about what is different between the two days and if there is something causing the storm to form on the stormy day that is not present on the sunny day. (Note: While there are several factors related to the difference, the available moisture in the atmosphere is an important one.) Give students an opportunity to discuss their ideas in small groups, followed by whole group discussion.

This is your opportunity to informally assess what students already know about the relationship between storms and the water cycle. Below are examples of beginning and developing student ideas:

- **Beginning:** *The water vapor goes up in the air. There is more evaporation.*
- **Developing:** *Evaporation was caused by heat. The heat and evaporation traveled up from the ground. The Sun’s energy warms the water and it evaporates and goes up to the clouds.*

6. **Record ideas to the Model Idea Tracker.** Find a visible place in the classroom that will be used to record student ideas about how storms form (e.g., chart paper, PowerPoint, smart board, or whiteboard). This is the Model Idea Tracker, and it will be used repeatedly through GLOBE Weather. The tracker is a place to record consensus ideas that are helpful for explaining moisture in the atmosphere and precipitation. At this point in the lesson sequence, students may have inaccurate or incomplete ideas, which is important to be aware of moving forward. Do not record ideas to the Model Idea Tracker if the idea is not agreed upon.

Model Ideas:

- Evaporation of water at the surface is important for clouds/storms.
- Evaporation happens because of heating from sunlight.
- Clouds form when water condenses.



Assessment

Listen closely to how students discuss evaporation, heating, and how water gets up to the clouds. These science concepts will be developed throughout this learning sequence.



Developing & Using Models

The Model Idea Tracker is used to record consensus ideas that help explain a phenomenon. These ideas are generated by students and agreed upon as a class.

Students develop a diagrammatic model as part of their Working Model for an Isolated Storm. Working Models capture important pieces of the system but are not comprehensive.

DIAGRAM OF A STORM FORMING



1. **Tell the story of a thunderstorm forming throughout the school day.** *“Let’s imagine together a storm that might form throughout the day. You wake up to a blue sky. During the morning, a few small clouds appear. By lunch, there are more clouds, and they are much larger. By the end of the school day, it’s raining! The rain does not last all night, and by the time you go to sleep, stars are visible because the clouds are gone.”*
2. **Direct students to construct a time series diagram using Lesson 2: Step 3 on their activity sheets.** The purpose of the time series diagram is to focus students on how storms change over time and what might be different at various moments over the course of a storm. The time series diagram is the first part of their Working Model for an Isolated Storm. They can revisit their diagrams throughout the learning sequence and especially as they work toward a Consensus Model later in this sequence. (Note: Students will not yet know the term “isolated storm” since this is the first type of storm that they are investigating in depth. The term is first used with students in Lesson 5, although you may wish to modify and add it earlier.)
3. **Share and discuss the diagrams.** Prompt students to explain what is different in each stage of the storm and why they think there is a difference. As students share, use the following prompts to get them to think about measurements they may want to see to better understand the storms:
 - *In the diagrams, we can see that the clouds are high above the ground. If you could somehow investigate the air up high compared to the air near the ground, what do you think you would see?*
 - *What are some measurements you would want to take of the air from different altitudes? How might those measurements help us figure out how clouds start to form on a sunny day?*

LESSON 2

STEP 3

FORMATIVE ASSESSMENT

One way to assess your students’ learning in an Engage lesson is to ask students to comment on important ideas they learned in the lesson. Consider using an Exit Ticket or home learning assignment to do this. For the Exit Ticket, have students write down their ideas to the questions below on an index card and hand it to you as they leave the classroom. For a home learning activity, have students respond to the questions in their science notebooks and be prepared to share their ideas in the following class.

- **What?** Write one idea or concept that you found particularly interesting.
- **So what?** Write why that concept or idea is important.
- **Now what?** Think about how your thinking changed based on that new idea.



Have students share their responses with a partner or with the rest of the class.



Storyline Link

This question set is a critical link to maintain coherence as students move between Lesson 2 and Lesson 3 to motivate analysis of weather data.



Assessment

This assessment can give you insight as to what students understood as important ideas from the lesson and whether these are similar to the Model Ideas generated by the class.

SKY WATCHING



LESSON 2 STEP 4

Up until now, students have mostly discussed clouds and storms using video and images made by other people. Nothing can match the real experience of making observations outdoors. For *Lesson 2: Step 4* choose either Option 1 or Option 2 below.

OPTION 1: Cloud Observations

Consider doing an outdoor cloud observation together as a class, identifying cloud types using the [GLOBE Cloud Chart](https://globe.gov/globecloudchart) (globe.gov/globecloudchart). Then assign a project or home learning activity where students make a time-lapse video of clouds using their device and then make observations from their videos. Time-lapse videos are particularly powerful to see change over time and can be an engaging project for your students. The following example questions can guide discussion around their videos and observations:

- *What did you notice happening to the clouds over time?*
- *Did the clouds change shape or color?*
- *Did you notice patterns in clouds at certain times of day?*

OPTION 2: GLOBE Cloud Protocol

The GLOBE Cloud Protocol, in which students either use the [GLOBE Observer Cloud app](https://observer.globe.gov) (observer.globe.gov) or the [GLOBE Cloud Chart](https://globe.gov/globecloudchart) (globe.gov/globecloudchart) with the [GLOBE Cloud Protocol](https://www.globe.gov/web/s-cool) (<https://www.globe.gov/web/s-cool>), are excellent ways to help students make in-depth observations of their environment. The required materials and time will vary depending on how you collect your observational data and use the data entry system. The Cloud Protocol is part of the [Atmosphere Protocols](https://www.globe.gov/do-globe/globe-teachers-guide/atmosphere) (<https://www.globe.gov/do-globe/globe-teachers-guide/atmosphere>).



Planning & Carrying Out Investigations

Making time-lapse videos supports students in conducting investigations to produce data. Students can make observations from their videos to answer questions or explain phenomena.

The GLOBE Cloud Protocol takes student-driven investigations to a deeper level. The process of collecting and entering cloud data as part of the GLOBE community supports students in authentic science investigations where their ground observations contribute to a joint effort with NASA scientists.

LESSON
3

TEMPERATURE CLUES

How does temperature relate to cloud formation?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(90 minutes, plus optional activity)	
<p>Temperature: Ground to Clouds Students collect simulated air temperature data from near the ground to an altitude of about 10 kilometers. Students identify a pattern in the data that temperatures are warmer near the surface and cooler as altitude increases in the troposphere.</p>	<p>Lesson 3: Student Activity Sheet </p> <p>Weather video (scied.ucar.edu/video/weather-balloon-launch)</p> <p>Virtual Ballooning simulation (scied.ucar.edu/interactive/virtual-ballooning)</p>
<p>Surface Temperature and Air Temperature Students look closer at temperatures near the surface to make sense of why air temperatures near the ground are warmer than air temperatures higher in the troposphere. They analyze surface temperature and air temperature data that show surface temperatures are warmer than air temperatures.</p>	
<p>Option: GLOBE Air and Surface Temperature Students collect their own air temperature and surface temperature data for analysis using the GLOBE Air Temperature and Surface Temperature protocols. Students also collect data from a variety of surfaces to see how the kind of surface influences temperature.</p>	<p>GLOBE Air Temperature and Surface Temperature protocols, (https://www.globe.gov/web/atmosphere/protocols)</p> <p>a thermometer, and an infrared (IR) thermometer</p>
<p>Model: Heating Earth's Atmosphere Students use their temperature data to develop a Working Model explaining how Earth's atmosphere is heated from the surface below and not directly from the Sun above.</p>	<p>Colored pencils</p>



TEMPERATURE CLUES

How does temperature relate to cloud formation?



NGSS Sensemaking

The purpose of this series of activities is to see temperature as a potential factor in storm formation. The temperature gradient from the surface to the clouds is an important one, and students will cycle back to the temperature pattern throughout this sequence. This series of activities also helps students make sense of the underlying mechanisms that cause the observed pattern and focuses students on explaining why the surface is warmer than the air above it. A common misconception is that air in the atmosphere is heated directly from sunlight above and not from the surface below. Understanding heating of Earth's surface is an important piece of a convective model of storm formation.

PERFORMANCE OUTCOME

- Collect and analyze data to identify patterns that describe the relationship between temperature and altitude.
- Analyze and interpret data to describe differences in surface temperature and air temperature during a day.

NGSS DIMENSIONS (GRADES 6-8)

- Weather is influenced by interactions involving sunlight, the atmosphere, and land.
- Collect data to produce data to serve as the basis of evidence to answer scientific questions.
- Analyze and interpret data to provide evidence of phenomena and to identify temporal relationships.
- Develop a model to describe unobservable mechanisms.
- Ask questions to clarify and/or refine a model.
- Use graphs to identify patterns in data.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon.
- Patterns of change can be used to make predictions.

Teacher Procedures

Collect Temperature Data

1. **Navigate from the previous lesson.** During the previous lesson, the following questions were posted and can be used to introduce this lesson:

- *In the diagrams (Lesson 2: Step 3) we can see that the clouds are high above the ground. If you could investigate the air up high compared to the air near the ground, what do you think you would see?*
- *What are some measurements you would want to take of the air from different altitudes?*
- *How might those measurements help us figure out how these clouds form?*

2. **Show a video of a weather balloon launch.** The video shows how weather balloons are launched to take measurements in the atmosphere, and temperature is one of those important measurements.



UCAR WEATHER BALLOON VIDEO

[This video shows scientists launching a weather balloon \(2 minutes\).](#)

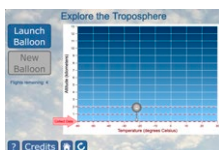
(scied.ucar.edu/video/weather-balloon-launch)

LESSON 3 STEP 1

3. **Make predictions of how temperature changes from the surface to altitudes where clouds form.** Direct students to the *Lesson 3: Student Activity Sheet*. Read the instructions together. Tell students to imagine a weather balloon collecting temperature data as it goes up in the atmosphere. Ask students to make predictions about temperature from the ground to the height of clouds in *Lesson 3: Step 1* and to share those predictions in small groups.

LESSON 3 STEP 2

4. **Arrange students in groups with computers or tablets for the Virtual Ballooning simulation.** Explain to students that they will collect data from a simulation of weather balloon data. Orient students to the Virtual Ballooning simulation and discuss how they should collect and record temperature data in *Lesson 3: Step 2*, which prepares students for the simulation.



UCAR Virtual Ballooning Simulation

(scied.ucar.edu/interactive/virtual-ballooning)

Note: Students should choose “Explore the Troposphere” within the interactive.

LESSON 3 STEP 2

5. **Students collect temperature data and record it on their activity sheet in Lesson 3: Step 2.**



Storyline Link

This question set is a critical link to maintain coherence as students move between Lesson 2 and Lesson 3 to motivate analysis of weather data.

LESSON
3
STEP 3

6. **Students work with peers to analyze the data (Lesson 3: Step 3, Questions 1 and 2) and interpret the data (Lesson 3: Step 3, Questions 3 and 4).** Conduct a class discussion focusing on students' ideas about these questions and working toward the key pattern:

KEY PATTERN: *Temperature is warmer near Earth's surface and temperature decreases as the weather balloon moves higher into the atmosphere where clouds/storms form. (Note: This pattern holds true in the troposphere.)*

As students discuss this pattern, elicit other first-hand or second-hand experiences they've had related to Earth's warmer air temperatures at lower altitudes and the air being cooler higher in altitude/elevation. Probe students' initial ideas about why this pattern might occur.

7. **Discuss the final question: How does temperature relate to clouds as an isolated storm forms?** Encourage students to use what they figured out about temperature and altitude to reconsider what might be happening in the Anchoring Phenomenon or storm formation in general. Students can discuss specific storms at this time or more general patterns they notice about temperature and storms.
8. **Transition to the next activity.** Use the following questions to get students thinking more about temperatures near the surface of Earth:
- *If we were able to look closely at different altitudes, from near the surface to high in the sky, what temperature pattern would you expect to see?*
 - *How do you think the results would compare if we measured temperature throughout a school day?*

COMPARING SURFACE TEMPERATURE AND AIR TEMPERATURE DATA


LESSON
3
STEP 4

Planning note: If you want students to focus only on data analysis, you can use the data set provided in the activity below. If you'd like students to collect their own data, have students collect air temperature and surface temperature data following [GLOBE Atmosphere protocols](https://globe.gov/do-globe/globe-teachers-guide/atmosphere) (globe.gov/do-globe/globe-teachers-guide/atmosphere) and replace Lesson 3: Step 4 on the activity sheets with your students' data.

DATA ANALYSIS ONLY OPTION

1. **Navigate from the previous activity.** Have students explain the temperature patterns they observed in the Virtual Ballooning investigation. Remind students of questions at the end of the last activity in order to set a purpose for analysis of the next data set:
- *If we zoomed in to this part of the altitude where we live, what temperature pattern would you expect to see?*
 - *How do you think the results would compare if we measured temperature throughout a school day?*

**** If doing the GLOBE Surface Temperature and Air Temperature protocols, introduce the protocols here. Students do not need to complete the data analysis on the Longmont Data Set below because they can analyze their own data set.****



Patterns in Data

Students identify a temperature pattern related to the heating of Earth and storm formation.



Storyline Link

Use these two questions to review where students ended up in the previous activity.

2. **Introduce students to the data set.** Describe where the air temperature and surface temperature data was collected, over what time period, and how it was collected. (See description below.)

WESTVIEW MIDDLE SCHOOL DATA SET

Middle school students in Longmont, Colorado wanted to know how the ground temperature (surface temperature) compared to air temperature. They measured both temperatures over a school day. Their surface temperature data were measured on their school track and their air temperature thermometer was located on the school roof. The students agreed these two surfaces were the most similar, which is why they selected the school track for their surface temperature location. They measured both temperatures every hour during the school day. They also made observations of cloud cover.

3. **Use the Identify and Interpret (I²) Sensemaking Strategy to analyze and interpret the graphed data.** Orient students to the graph in terms of the axes, the data lines showing surface and air temperature data, and the cloud cover notes at the top of the graph.



- a. **Write “What I See” statements.** To do this, students write observations of the data in the graph. Students draw the “What I See” icon followed by their observation (e.g., “The surface temp line on the graph is always above the air temp line”). Students also draw an arrow to the part of the graph that corresponds to their observation. Remind students to avoid “because” statements and focus on observations only. Conduct a short discussion highlighting where students have similar or different observations.



- b. **Write “What It Means” statements.** To the side of each “What I See” statement (observation) students draw the “What it Means” icon and then an explanation (e.g., “The surface is warmer than the air”). Each What I See statement should have a What it Means statement next to it. These statements are students’ interpretations of what is happening in each part of the graph. Conduct a discussion about students’ ideas. Because students are still exploring, it is okay for them to have incomplete explanations. Focus on accurate observations and logical, even if incomplete, explanations.



Data Analysis & Interpretation

The I² Sensemaking Strategy is an instructional strategy to frame the process of data interpretation. When used with graphical data, students make observations and interpret parts of a graph before looking at the graph as a whole.

Option: GLOBE Air and Surface Temperature Data Collection

Collecting surface temperature data is a highly engaging activity for students. They enjoy exploring how surface temperature varies across the day and across different kinds of surfaces. Use the GLOBE Air Temperature and GLOBE Surface Temperature protocols to conduct this investigation. There are several options for how to gather the data, but if time and equipment permit, students should collect surface and air temperatures over a variety of surfaces to compare their relationships and whether they change depending on the surface. See the GLOBE Connections section of the GLOBE Weather website if you/your students are interested in using these observations as a starting point to a GLOBE Investigation.

MODEL: HEATING EARTH'S ATMOSPHERE

1. **Ask students to share what they learned from the surface temperature and air temperature analysis.** Have students reflect on how the Virtual Ballooning data and the Longmont Data Set have informed their thinking. One important finding is that the surface is warmer than the air above it but that the two temperatures mirror each other as the Sun heats the Earth. Add this idea to the Model Idea Tracker.

Model Ideas:

- The surface is warmer than the air above it.
- The air near the ground is warmer than air closer to where clouds form.

3**STEP 5**

2. **Introduce the Working Model for explaining temperature patterns.** In *Lesson 3: Step 5*, students will develop a Working Model of surface heating to explain temperature patterns, with the ground surface having the warmest temperatures and temperature decreasing with altitude. This is a Working Model because it's a work in progress and does not capture a complete representation of the system, only part of the system.
3. **Draw and label a Working Model individually.** Before students begin their model, preview the items listed on *Lesson 3: Step 5* of their student activity sheets to provide guidance about what their models need to explain and the question their models are trying to answer: *"Why does the surface temperature warm over the day, and why is the surface warmer than the air above it?"* Their models should describe connections between sunlight heating Earth's surface and the temperature pattern they've observed, particularly why the surface is warmer than the air above it, which leads into the next lesson on warm air rising. These models will vary in sophistication based on prior learning of particle models, temperature, and thermal energy transfer.
4. **Share and revise Working Models in small groups.** Arrange students in small groups to share their models. Students should revise their models based on feedback from their group.
5. **Discuss Working Models in whole group discussion.** Have students share how they represented different parts of the model and allow the students time to debate how they want to represent those parts as a class. Students can make edits to their models as the class discusses these models. As students discuss their thinking, check the Model Idea Tracker to add to the tracker or update the Model Ideas.

Suggested prompts for discussion:

- *Why do we think surface temperature is warmer than the air temperature above it?*
- *How is the warm air moving? Does this match our temperature pattern?*
- *More advanced question for students with prior knowledge on particles and temperature: What's happening to the air molecules when they are heated near the surface?*

3**STEP 6**

6. **Connect the Working Model to an isolated storm.** In *Lesson 3: Step 6*, have students discuss their ideas about how the temperature patterns relate to the formation of clouds and storms. In particular, have students think about why these types of storms tend to happen in the afternoon, after the Sun has been up for hours.

**Developing & Using Models**

In this activity students use temperature data patterns to generate more Model Ideas for their Model Idea Tracker. Then they develop a Working Model to explain the heating of the atmosphere from below, as opposed to heating from above directly by the Sun. This is an important mechanism in the system.

LESSON
4

FUEL FOR STORMS

What is different about a sunny day and a stormy day?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(80 minutes)	
<p>Data Analysis: Sunny and Stormy Day Students analyze temperature and humidity data on a sunny day and a stormy day. They find different patterns in both. On a sunny day, temperature increases, while relative humidity decreases. On a stormy day, this normal pattern begins, but then changes, as humidity rises. This leads students to think about humidity as a critical variable in storm formation to add to their Model Idea Tracker.</p>	<p>Lesson 4: Student Activity Sheet </p>
<p>Bottle Model Lab / Demonstration Students create models using soda bottles to simulate what happens when temperature increases when there is moisture present and when no moisture is present. Large bodies of water can be a source of moisture, but there is also moisture present in the ground as demonstrated in the bottle model systems.</p>	<p>Three bottles, water, sand/dirt, thermometers, lamp, funnels, rubber stoppers, clock/timer</p>



FUEL FOR STORMS

What is different about a sunny day and a stormy day?



NGSS Sensemaking

The purpose of this series of activities is to see moisture as a key factor in storm formation. Students learn that warm temperatures coupled with a lot of moisture are good conditions for storms. The measurement used for moisture is humidity. If either warm temperatures or humidity are missing from the system—for example cool temperatures or not enough moisture—then there is less chance for a storm.

PERFORMANCE OUTCOME

- Analyze and interpret data to identify differences in patterns in air temperature and humidity during stormy days and sunny days.
- Conduct an experiment and collect and analyze data to compare changes in humidity in sunny and in stormy conditions.

NGSS DIMENSIONS (GRADES 6-8)

- Water continually cycles among land, ocean, and atmosphere via evaporation, condensation, and precipitation. Global movement of water and its changes are propelled by sunlight. Weather is influenced by interactions involving sunlight, the atmosphere, and land.
- Analyze and interpret data to provide evidence of a phenomenon.
- Collect data to produce data to serve as the basis of evidence to answer scientific questions.
- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.
- Use graphs to identify patterns in data.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Patterns of change can be used to make predictions.

Teacher Procedures

Data Analysis: Sunny and Stormy Day

1. **Navigate from the previous activity.** At the end of the previous activity, students discussed how temperature could be related to storms forming. Have students review their ideas before beginning the next activity.
2. **Brainstorm ideas about a sunny day vs. a stormy day.** Get students thinking about data comparisons between a sunny day and a stormy day.

Pose the following questions:

- How can one day be warm and sunny, while the next day is still warm but with an isolated storm? What is different about the two days?
- What weather measurements might help to answer these questions?

LESSON 4 STEP 1

3. **Orient students to the sunny day and stormy day data.** Direct students' attention to *Lesson 4: Step 1* of their student activity sheets. Students will compare air temperature on a stormy day and a sunny day. You can use the I² Sensemaking Strategy, or another graph interpretation strategy, for this activity.

SUNNY DAY AND STORMY DAY DATA

The temperature and (relative) humidity data set comes from a local automated weather station in Albuquerque, New Mexico. The data can be found online through Weather Underground and the U.S. National Weather Service. The July 29, 2017 plot is from a sunny day, while it was a stormy day on July 31, 2017.

4. **Analyze the sunny day and stormy day data.** Give students time to analyze and interpret the graphs in partners or small groups. Encourage students to write on the graphs using WIS and WIM statements if using the I² Sensemaking Strategy.
5. **Identify air temperature patterns.** Ask students to describe the sunny day and stormy day temperature patterns. Ask students to share and compare the patterns they observed in the air temperature graphs. The following two patterns should emerge from these discussions:
 - **Sunny pattern:** Temperature gradually warms and then gradually cools on a sunny day
 - **Stormy pattern:** Temperature gradually warms but then quickly cools in the afternoon

Have students circle on their stormy day graph when they think it rained. Ask students to write an explanation about their choice and share their ideas with their group. Prompt several students to share their ideas aloud during whole group discussion. Encourage students to explain what they see in the temperature data that indicates a storm.

LESSON 4 STEP 2

6. **Identify humidity patterns.** Direct students to *Lesson 4: Step 2*, which is the second set of graphs showing humidity over the same times. Tell students that humidity is a way to measure the amount of water vapor, or moisture, in the air. Use the I² Sensemaking Strategy to help students analyze and interpret the humidity graphs. Ask students to describe the sunny day and stormy day humidity patterns. Ask students to share and compare the patterns they



Storyline Link

Link back to the stormy and sunny day time-lapse videos to get students wondering about other factors related to storms.



Data Analysis & Interpretation

Students analyze temperature and relative humidity data on a sunny day and a stormy day.



Patterns in Data

Students identify important temperature and humidity patterns that are different between a sunny day and a stormy day.

observed in the humidity graphs. The following two patterns should emerge from these discussions:

- **Sunny pattern:** Humidity begins high but goes down during the day
- **Stormy pattern:** Humidity begins high and starts to go down, then it climbs really high, really quickly in the afternoon/early evening

Have students circle when it rained on their stormy day humidity graph. Ask students to write an explanation about their choices and share their ideas with their group.

- 7. Compare air temperature and humidity for a stormy day.** Using both data sets, when does the class think it rained? What were the temperature and humidity conditions that led to this event? Have students articulate what the temperature and humidity was like before, during, and after the storm through a whole class discussion.
- 8. Add new ideas to the Model Idea Tracker.** Have students generate new ideas about the stormy day using the air temperature and humidity patterns. Record these on the Model Idea Tracker.

Model Ideas:

- Rising temperature and humidity are good conditions for an isolated storm.
 - Rising temperature and low humidity are not good conditions for an isolated storm.
- 9. End the discussion transitioning to the next activity on bottle models:** *"If we created a system with warm temperatures and lots of moisture, it would rain. But if we didn't have warm temperatures or enough moisture, do you think it would rain or not? Let's see if we can try this out."*

BOTTLE MODEL LAB / DEMONSTRATION

Planning note: The Bottle Model activity can be completed as a lab or a demonstration. There is also a time-lapse video that can be used if time and materials do not allow for a lab or demonstration. Make the necessary modifications to meet your students' needs based on your available equipment. The purpose of this demonstration is to help students connect the data measurements they just analyzed with visual evidence they can see. The instructions below are written for a class demonstration. See the following page for a description of the demonstration set-up.

- 1. Navigate from the previous lesson.** In pairs, have students describe the temperature and humidity patterns for a sunny day and a stormy day. Introduce that we are going to test these conditions to see if they can create "storms" and "no storms" in a small system.
- 2. Use temperature and humidity patterns to brainstorm how to build a storm in a bottle.** Ask students to use what they have learned about temperature and humidity to make a storm in a bottle. Provide students with a general idea of how to set-up the experiment and a list of possible materials, but allow students to brainstorm what they would add to a bottle to form a storm versus what they would add so as not to form a storm.
- 3. As a class, decide on two systems, one "sunny day" (no storm) bottle; one "stormy day" (storm) bottle, to test.** Ask student volunteers to help insert the necessary materials into the bottles using a funnel. For wet sand/dirt, insert the dry sand or dirt first, then add water.
- 4. Diagram the lab set-up.** Direct students to *Lesson 4: Step 3* to draw the lab set-up and to label the parts of each system and what those parts represent.

LESSON
4

STEP 3



Developing & Using Models

Using patterns in temperature and humidity data, students add to their Model Idea Tracker.



Storyline Link

This closing sets the stage for the bottle model lab/demonstration and a need to test out students' initial ideas about temperature and humidity.



Storyline Link

Setting the stage for the bottle model lab/demonstration is important so that students connect the data they analyze to the observation they make of the bottles.

LESSON
4
STEP 3

5. **Discuss, as a whole group, students’ predictions about which conditions will lead to the best storm and why (and vice versa).** Specifically, talk about what we expect to see if we have created conditions for a storm to form (e.g., *Will it actually “rain” inside the bottle? What might we see?*). Remind students that water vapor isn’t visible and review the parts of the water cycle this activity will demonstrate (focus on evaporation and condensation). Look at the data table (*Lesson 4: Step 3*) and point out that temperature should be measured every 2 minutes. Decide as a class what will be recorded in the humidity column of that data table (e.g., *Will students record when condensation is visible vs. not visible?*).
6. **Turn on the lamp and let the demonstration run for at least 15-20 minutes.** The higher the watt bulb used, the quicker your students will see results. You can run this lab as long as you need to see a temperature change and condensation.



Planning & Carrying Out Investigations

Include students in the planning of the bottle model lab/demonstration. Prompt students to articulate why certain conditions should be tested to help them figure out the best conditions for storms.

BOTTLE MODEL DEMONSTRATION

TIME:

- Set-up will take approximately 10 minutes depending on how many bottles you want to test.
- Results appear within 20 minutes of turning on the lamp.

MATERIALS:

- 100-watt incandescent bulb and lamp (e.g., clamp lamp).
- Two or more clear plastic soda bottles or transparent containers.
- Two or more thermometers.
- Rubber stoppers with a hole (optional).
- Funnel.
- Dried sand or soil.
- Water.

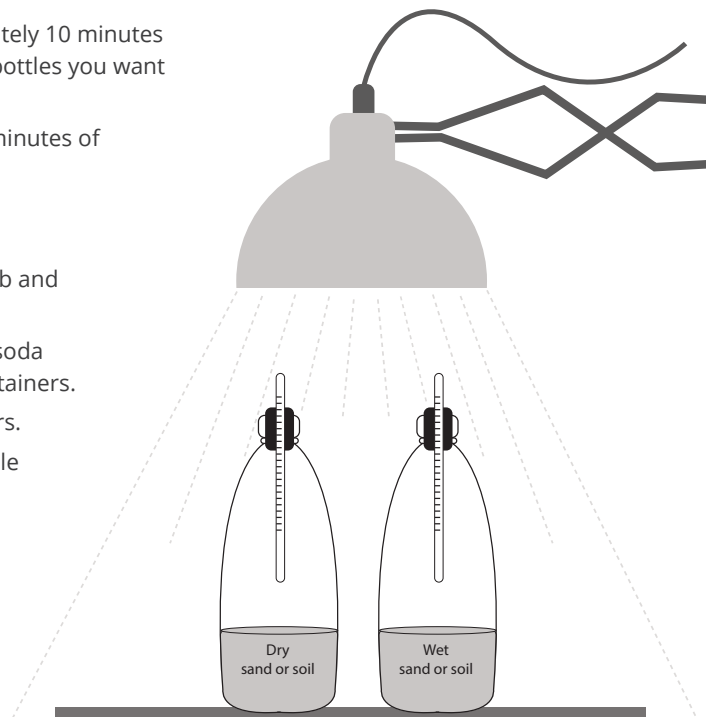
TIPS AND ADVANCE

PREP:

- If not using rubber stoppers, punch a hole in the bottle lid to insert the thermometers.
- Thermometers may become difficult to read with condensation.
- Insert dried sand/soil into the bottle before making it damp. It will be easier and cleaner to pour to avoid getting sand on the side of the bottle. Be careful to minimize the material that gets on the inside of the bottles. You want the sides of the bottles to remain as clear as possible so students can measure temperature and observe condensation.

VIRTUAL RESOURCES:

[Bottle Model time-lapse video](https://scied.ucar.edu/video/globe-weather/bottle-model-timelapse) (scied.ucar.edu/video/globe-weather/bottle-model-timelapse)



LESSON
4
STEP 3

7. **Make observations of the bottles.** Have students make observations of the bottles and record temperature measurements in a data table (*Lesson 4: Step 3*). Use a clock or timer to keep track of the time and have students record observations every 2 minutes.
8. **Discuss and compare results.** Give students an opportunity to discuss the questions on their activity sheets in small groups or using a collaborative group strategy.

Discussion questions:

- *How did the sunny day bottle match/not match what you expected?*
 - *How did the stormy day bottle match/not match what you expected?*
 - *Changing the amount of water in the system (humidity/moisture) was important. If a town is located far from an ocean or large body of water, where does the water come from?*
 - *Using evidence from the bottle models and the temperature and humidity data in Lesson 4: Step 1 and Step 2, what conditions are best for storms?*
9. **Transition to whole group discussion.** Specifically focus on the importance of the source of water and the best conditions for a storm. In the water only condition, the source of water might represent large bodies of water or the ocean. In the damp soil/sand condition, the source of water represents groundwater and smaller surface water sources. Prompt students to connect their observations back to the temperature and humidity patterns observed for a sunny and stormy day. Add to the Model Idea Tracker as students come to agree upon the role of moisture.

Model Idea:

- A source of moisture is important to get water into the atmosphere for storms.
10. **Look ahead to the next lesson.** End the discussion, posing the question: “*How did the water from the bottom of the bottle get up on the sides of the bottle?*” Have students share their initial ideas to this question.



Developing & Using Models

Add to the Model Idea Tracker the critical role of a water source for storm formation.



Storyline Link

Students will be investigating convection next, so they need to start thinking about how water at the surface moves up in the atmosphere.

LESSON **5**

AIR ON THE MOVE

How does air move and change when a storm is forming?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(100 minutes)	
<p>Demonstration: Warm and Cool Air Students watch a demonstration of warming up and cooling down air inside a Mylar balloon that has been partially deflated. Students discuss what they think happens to cause the balloon to go up or down.</p>	<p>Lesson 5: Student Activity Sheet </p> <p>Mylar balloon with helium Hair dryer</p>
<p>Interactive Reading: Air on the Move Students read about the warming of air and evaporation of water at the surface and how this air moves during convection. Students make illustrations of concepts throughout the reading and connect back to previous evidence they have collected.</p>	<p>Colored pencils</p>
<p>Consensus Model: Isolated Storm The class works together to construct a class Consensus Model for explaining the best atmospheric conditions for storms. Students pull together ideas from their previous Working Models to create a comprehensive model to show how moisture becomes available in a location, increasing the chance of an isolated storm.</p>	<p>Whiteboard, smart board, or chart paper and markers (for the Driving Question Board and Model Idea Tracker)</p> <p>Whiteboard or chart paper and markers (to make the Consensus Model)</p>



AIR ON THE MOVE

How does air move and change when a storm is forming?



NGSS Sensemaking

This series of activities will help students to piece together different parts of a model they've been working toward in previous lessons. The goal is for students to identify important underlying mechanisms and processes that explain how moisture becomes available over a location in an isolated storm. Students use evidence from their investigations to vet the emerging model against their Model Ideas, or the rules of the system.

PERFORMANCE OUTCOME

- Conduct an experiment and analyze and interpret data to describe how changes in temperature in a body of air cause the air to change and move.
- Develop and use a model to explain how energy from the Sun, convection, water on the surface and in the air, and variations in temperature and humidity create conditions/cause the formation of isolated storms.

NGSS DIMENSIONS (GRADES 6-8)

- Global movement of water and its changes are propelled by sunlight. Weather is influenced by interactions involving sunlight, the atmosphere, and land.
- Analyze and interpret data to provide evidence of a phenomenon.
- Collect data to produce data to serve as the basis of evidence to answer scientific questions.
- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events.

Teacher Procedures

Demonstration: Warm and Cool Air

1. **Navigate from the previous lesson.** At the end of the previous lesson, students shared their ideas about how water at the surface (near the bottom) of their bottles got onto the upper parts of the bottles.

Review this discussion using the following question prompts:

- *What happened to the water at the surface before it traveled to the top of the bottle?*
 - *What happened to the water at the top of the bottle?*
 - *How did that water get up there? Why would it go up?*
2. **Motivate the need to investigate vertical movement of air.** Students may say evaporation is how water at the surface gets higher in the atmosphere. Remind students about the water cycle. Talk about what evaporation means and how it explains the change of liquid water to gas but not how it travels upward. (Consider whether students need additional support to understand processes of the water cycle.)

Suggested transition:

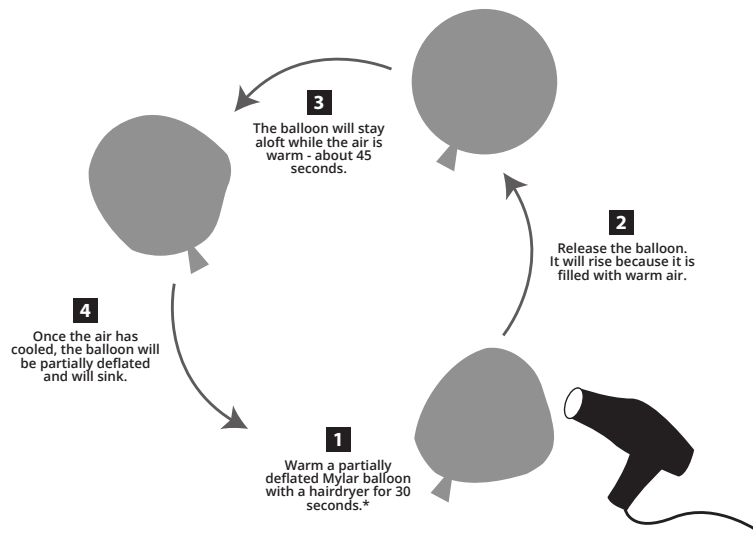
- *“So we know the surface is warmed here and water evaporates, and we know water condenses up here because it’s cooler, but how and why does the water vapor travel up? We need to figure this out. If we add heat to air down here, can we get the balloon to travel up?”*
3. **Elicit student experiences of warmed air and steam.** Ask students to think about why recently warmed water vapor would travel up. Broaden the discussion to elicit students’ experiences of warmed water vapor (e.g., steam) and warmed air (e.g., “heat waves” off highways). Point out a pattern that this warm air seems to move up. Ask students why they think warm air moves upward.
 4. **Introduce students to the Mylar balloon investigation.** The Mylar balloon contains helium gas, and students are going to heat the gas to see if they can get the balloon to move upward.



Storyline Link

This move establishes the need to explain air traveling upward. Students might think evaporation is sufficient. They need help seeing they are missing a piece to their models.

MYLAR BALLOON DEMONSTRATION

**TIME:**

- Set-up is less than a minute
- *The time it takes for the balloon to visibly inflate will vary (typically 20-60 seconds)
- The balloon will stay aloft for about 45 seconds before deflating and sinking back to the floor

MATERIALS:

- Partially deflated Mylar balloon filled with helium. Needs to be lightly rested near the floor
- Hair dryer
- Straw

TIPS AND ADVANCE PREP:

- Deflate the balloon by inserting a drinking straw three-quarters of the way into the hole near the base of the balloon. Lightly squeeze some air from the balloon but avoid emptying the balloon too much. Prepare a few extra balloons in case a one or more don't function properly.
- If you have an IR thermometer, consider taking temperature measurements of the balloon just before, as it's being heated, and as it cools.

VIRTUAL RESOURCES:

- Demonstration video: [Warming a Mylar Balloon](https://scied.ucar.edu/video/warming-mylar-balloon) (scied.ucar.edu/video/warming-mylar-balloon)

5
LESSON
STEP 1

- 5. Draw the lab set-up.** Direct students to *Lesson 5: Step 1* of their student activity sheets. Ask students to draw the demonstration set-up on their activity sheets.
- 6. Warm the Mylar balloon.** Have a student volunteer to warm the Mylar balloon using a hair dryer. It is important to represent the balloon as a pocket of air located at the surface of Earth. The hair dryer should represent thermal energy radiated from the ground and not light energy from the Sun above.

LESSON
5
STEP 1

- 7. Make observations of the balloon.** Students make observations of what they see and hear happening to the Mylar balloon as the air inside is warmed (e.g., crinkling as it expands and travels up to the ceiling). Prompt students to add these observations to their observation sheet in *Lesson 5: Step 1*. Continue observing the Mylar balloon as it cools (roughly one minute or less). Once the air inside the balloon cools, it begins to sink and visibly shrink. Prompt students to add observations to their observation sheets. Repeat the demonstration a second or third time with different student volunteers to make additional observations and to prompt students to start explaining what's happening in the balloon.
- 8. Develop an initial explanation.** Direct students to the questions at the end of *Lesson 5: Step 1* on their activity sheets. Students are prompted to explain what is happening inside the Mylar balloon as it is heated and when the balloon sinks. If students are new to particle motion and thermal energy, they may be more uncertain about what's happening in the balloon. You are steering them toward a basic understanding that warmed air molecules move more and are more spread apart, and vice versa for air molecules that have cooled. Students will encounter these concepts in the reading that follows. Encourage students to think about the balloon having the same amount of air, whether warm or cool, but changing in terms of volume, which they see when the balloon expands and contracts.

INTERACTIVE READING: AIR ON THE MOVE

LESSON
5
STEP 2

- 1. Navigate from the Mylar balloon investigation.** Students have initial ideas explaining the warm air inside the balloon traveling up. They likely need more information to put together the pieces of a convection model. Explain to students that reading more about the molecules in the air can help them figure out more of what's going on. Direct students to *Lesson: 5, Step 2*, an interactive reading called Air on the Move. Students will interact with the new information by drawing diagrams and summarizing new information.
- 2. Read the first two paragraphs and diagram warm and cool air.** The first part of the reading focuses on what happens when heat transfers to air molecules or when those molecules lose energy. Students draw diagrams to show warmed air molecules in a balloon moving faster and spread apart and cooler air molecules closer together and moving slower.
- 3. Read about how gravity affects air molecules.** Students read and draw air molecules low in the atmosphere at higher pressure and high at lower pressure (more spread out), which will help them understand why warm air rises. Have students label where "low pressure" and "high pressure" are on their drawings.
- 4. Read about convection.** Students read and look at a particle diagram showing how air molecules change during convection. After reading, pose the question: "How could convection be related to _____?" (e.g., the Mylar balloon, the bottle models, storms forming). Students are reminded about the relationship between water vapor and warm/cooled air (from *Lesson 4*). The vapor condenses from the air when the air reaches cooler temperatures.
- 5. Revisit explanations of warm air rising and add to the Model Idea Tracker.** Conclude the reading, reflecting on the question: "Why does warm air go up and cool air go down?" Students write their ideas on the reading first. As students share their thinking with the class, prompt students to connect to the previous phenomenon or data patterns they have seen in the unit (e.g., Mylar balloon, bottle models, isolated storm time-lapse videos, temperature patterns from the surface to the clouds), and how the new concepts help them explain what they observed.

Model Ideas:

- Warm air rises and cooler air sinks.
- Warm air is able to take in more water vapor compared to cool air.



Literacy Connection

Students interact with this reading by making connections and synthesizing new information with what they have learned previously.



Obtaining Information

Students read scientific text to determine critical concepts that help them explain phenomena.



Storyline Link

This is a critical moment in the Explain lesson where students start to use particle motion, convection, and humidity to explain phenomena.



Developing & Using Models

Add to the Model Idea Tracker new ideas about convection and humidity obtained from the reading and Mylar balloon investigation.

CONSENSUS MODEL FOR AN ISOLATED STORM

1. **Devote time to “taking stock” by returning to the Driving Question Board.** As you navigate from the reading and students’ recently developed ideas about air molecules, particle motion, and convection, have students reflect on what they have learned. Return to the Driving Question Board to see which questions students can now answer. As students review their questions and develop answers to some of those questions, use this information to inform how you approach the Consensus Model. It might be the case that students need to revisit a particular data set from earlier in the sequence to “refresh” their thinking and/or to make connections they have not made yet.
2. **Revisit the stormy day time-lapse video to motivate explanation of this phenomenon.** Replay the isolated storm time-lapse video, and have students work in small groups to discuss important things happening for the storm to form. Tell students they are going to develop a model to explain the isolated storm:
 - *“Let’s see if we can put together all the things we’ve learned to create a model that explains what’s happening for the storm to form.”*
3. **Revisit the Model Idea Tracker.** Use the Model Idea Tracker to review important “rules of the system”. These Model Ideas have evidence to support them and can help students make sense of how a system works. As students construct the Consensus Model for an Isolated Storm, they should pay attention that it is consistent with their Model Ideas.
4. **Prepare for the Consensus Model.** Direct students to *Lesson 5: Step 3* on their student activity sheets to record their ideas individually about how precipitation happens in an isolated storm. Tell students that after they develop their model, the class will construct a Consensus Model for an Isolated Storm that takes student model ideas into account.
5. **Develop a Consensus Model.** In a public space, draw the Consensus Model for an Isolated Storm as students share their thinking about important processes and conditions for storms. For each suggested addition, put the idea forth to the class for other students to clarify and add to before it is recorded on the class model. Specifically ask students to cite data or other evidence to support their ideas. A list of guiding questions is provided on the student activity sheet to help organize parts of the model.
6. **Record the Consensus Model.** After the class version of the Consensus Model for an Isolated Storm is complete, direct students to revise their models on their student activity sheets using a different color of pencil. Encourage students to represent their thinking in different ways if it helps them make sense of what’s happening in the model. They do not need to record the exact model constructed by the class, but they do need to record one that is consistent with the Model Idea Tracker.

LESSON
5
STEP 3



Assessment

Returning to the Driving Question Board allows for you and your students to assess the progress on their questions. You can formalize this assessment as much as you prefer, for example, asking students to write explanations to their questions or simply discuss their new ideas aloud.



Developing & Using Models

Students develop a model to explain an isolated storm phenomenon. The model is vetted against their evidence.



MAKING A THUNDERSTORM

Can we identify the best conditions for storms?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes)	
<p>Make a Thunderstorm Simulation Students test their models by manipulating parts of the models to see how changes to those parts influence storm potential. Students have the opportunity to confirm parts of their models and refine other parts based on this investigation.</p>	<p>Lesson 6: Student Activity Sheet </p> <p>Computers</p> <p>Make a Thunderstorm simulation (scied.ucar.edu/interactive/make-thunderstorm)</p>
<p>When Did It Rain? Students are given a set of data recorded over a two-day period. During the two days, it rained only once. Using what students know about the best conditions for precipitation, students identify the time it rained and develop an evidence-based explanation supporting their choice. This activity can be adjusted to serve as a performance assessment.</p>	
<p>Return to Driving Question Board / Assessment The class works together to construct a class Consensus Model for explaining the best atmospheric conditions for storms. Students pull together ideas from their previous Working Models to create a comprehensive model to show how moisture becomes available in a location, increasing the chance of an isolated storm.</p>	<p>Driving Question Board (used in Lesson 5) Assessment item bank</p>



MAKING A THUNDERSTORM

Can we identify the best conditions for storms?



NGSS Sensemaking

This series of activities helps students piece together different parts of a model they've been working toward in previous lessons. The goal is for students to identify important underlying mechanisms and processes that explain how moisture becomes available over a location in an isolated storm. Students use evidence from their investigations to vet the emerging model against their Model Ideas, or the rules of the system.

PERFORMANCE OUTCOME

- Collect, analyze, and interpret data to describe temperature and humidity conditions on the ground and in the clouds that create conditions/cause the formation of a storm.
- Analyze and interpret patterns in data to explain how and why humidity and temperature change around an isolated storm.

NGSS DIMENSIONS (GRADES 6-8)

- Global movements of water and its changes are propelled by sunlight. Weather is influenced by interactions involving sunlight, the atmosphere, and land.
- Analyze and interpret data to provide evidence of a phenomenon.
- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.
- Use graphs to identify patterns in data.
- Cause and effect relationships may be used to predict phenomena in natural systems.

Teacher Procedures

Make a Thunderstorm Simulation

1. **Navigate from the previous lesson.** Take a moment to review the Consensus Model for an Isolated Storm. Ask students if there are new questions from the Driving Question Board that they can now answer. Have students share these questions and answers with the class.
2. **Return to the Anchoring Phenomenon.** In small groups, prompt students to discuss what they now know about “causes” of precipitation and potential for precipitation. Have students share their thinking about the Anchoring Phenomenon and whether they believe the Consensus Model for an Isolated Storm is consistent with the Colorado storm. Discuss how the Colorado storm may fit or may not fit the Model Ideas. Note that students might also recognize that the length of the storm, which persisted for several days, does not fit the Consensus Model for an Isolated Storm.

Model Ideas from Learning Sequence 1:

- Evaporation of water at the surface is important for clouds/storms.
 - Evaporation happens because of heating from sunlight.
 - Clouds form when water condenses.
 - The surface is warmer than the air above it.
 - The air near the ground is warmer than air at higher altitudes, like where clouds form.
 - Rising temperature and humidity are good conditions for an isolated storm.
 - Rising temperature and low humidity are not good conditions for an isolated storm.
 - A source of moisture is important to get water into the atmosphere for storms.
 - Warm air rises and cooler air sinks.
 - Warm air is able to take in more water vapor compared to cool air.
3. **Motivate a reason to test their models.** Explain to students that it is important to test a model to make sure it is useful for figuring out a phenomenon and that it can become helpful for making predictions. If they can figure out the best conditions for strong storms with heavy precipitation compared to conditions for weaker or smaller storms with less precipitation, their models will do a better job explaining why certain storms bring more precipitation compared to other storms.
 4. **Introduce the Make a Thunderstorm simulation.** Direct students to the *Lesson 6: Student Activity Sheet*. Introduce students to the Making a Thunderstorm simulation, which allows them to manipulate the temperature and humidity parts in their models to see how changing parts of the model affects storm potential. Emphasize to students that if one variable in their models changes, the outcome changes. They will need to explain why a strong storm forms and also why weaker storms form based on changes they made to parts of the model.

LESSON
6

Make A Thunderstorm Simulation

(scied.ucar.edu/interactive/make-thunderstorm)



Storyline Link

Returning to the Driving Question Board can help to remind students of their initial questions at the start of the unit.



Developing & Using Models

Students use their models to predict storm potential and refine their models based on simulated data.



Systems and Systems Models

Students learn that changing one variable in the Systems Model can change the model entirely.



Developing & Using Models

Students use their models to make predictions and refine their models based on the evidence.

LESSON 6
STEP 1

- 5. Use the Consensus Model to make predictions.** Have students use their models to make predictions about the best conditions for storms. Students record their predictions in *Lesson 6: Step 1* of their activity sheets.

LESSON 6
STEP 2

- 6. Collect evidence from the simulation.** Arrange students in groups with a computer or tablet. Orient students to the simulation and give them instructions for recording data in *Lesson 6: Step 2*. Students collect data from the simulation. Walk around and monitor progress. Prompt students to explain the storm outcome in terms of conditions that helped a storm form and conditions that did not help a storm form.

Important patterns to identify from the simulation:

- Warm temperatures near the surface and colder temperatures higher in the atmosphere with high humidity are ideal conditions for thunderstorms.
 - If there is less of a temperature difference between the two altitudes, weaker storms may still form.
 - If there is low humidity, regardless of temperature, thunderstorms will not form.
- 7. Confirm and/or refine the Consensus Model.** As a whole group, return to the Consensus Model to confirm or refine the model. Prompt students to use data from the simulation to determine whether they can confirm the model or want to change part of the model.

WHEN DID IT RAIN?



- 1. Navigate from the previous activity.** Students understand how to use temperature and humidity to make sense of storm potential in convective storms, specifically isolated storms. Students will use what they know to identify a rain event and to construct an explanation about what happened leading up to this event. Use the Model Idea Tracker to provide students with guidance to help them pull together what they know to make a claim about when this type of rainstorm happens:

- *If the air near the Earth's surface needs to be warm and rise for a storm to form and the Sun heats the ground surface, which heats the air near the ground, then at what time of day would you expect a thunderstorm?*

LESSON 6
STEP 3

- 2. Orient students to the new data set.** Direct students to *Lesson 6: Step 3* on their activity sheets. Students examine historical temperature and humidity data to test whether their isolated storm models help them determine when a rain event occurred in Pompano, Florida.

Pompano Data Set

This data set comes from Pompano Beach High School (a GLOBE school) in Pompano, Florida. The temperature and (relative) humidity data from July 21-22, 2017, come from a WeatherBug automated weather station co-located with this GLOBE school. These automated stations record weather data daily every 15 minutes. These data can be found on the GLOBE Visualization Tool and the GLOBE Advanced Data Access Tool.

- 3. Analyze the data.** Allow students time to work individually or in groups to analyze the data and determine the time of the rain event. If students disagree, they should use evidence to argue for their choices.



Assessment

This activity can be used as an individual performance assessment if you feel your students are ready to demonstrate what they know. If your students need more practice with the concepts they should work on this task in groups.



Data Analysis & Interpretation

Students analyze temperature and humidity data to determine the likely moment of a rain event.



Patterns in Data

Students use patterns in the data to construct an explanation for a rain event.

4. **Share the precipitation data with students.** Project the precipitation data so that students can identify if they were correct in their identifications. Through a whole class discussion, prompt students to explain whether their decisions were correct or incorrect and to share.

DRIVING QUESTION BOARD / ASSESSMENT



1. **Provide time for students to update the Driving Question Board.** Ask students to return to the board to answer questions, make changes to questions, and/or add new questions. Have students share aloud the new answers they have and/or new questions they want to add.
2. **Return to the Anchoring Phenomenon again.** Ask students: “Did the Colorado storm happen in the afternoon?” Students might remember that the video revealed that the storm lasted several days. Ask students what parts of their models might explain the event and what they think could be different. Since the Colorado event lasted much longer than the typical isolated storm, something else might be going on in that type of storm. Use this to initiate further investigations into different kinds of storms that students will explore in Learning Sequence 2.

For example:

- *“Our model helps us explain some kinds of storms, but the storm in Colorado lasted a lot longer. The Colorado storm might be a different kind of storm, so we need to do some more investigating to figure it out.”*
3. **Emphasize the power and limitation of models.** Have students talk about the kinds of storms that their models explain well, but also the types of storms that do not fit their models. Explain to students that models are tools to help us explain things happening in the world but that they are not always perfect and cannot capture everything. This is especially true for models of complex systems like weather, which is why weather is predicted probabilistically.
 4. **Assess student learning with the Learning Sequence 1 assessment.** You can find the assessment item bank and rubric in the Assessments section of *GLOBE Weather*.



Home Learning

Ask students to start thinking about storms that fit their models and storms that do not fit their models. They should come prepared to share their ideas at the next class.



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TEACHER GUIDE

TEACHER GUIDE



LEARNING SEQUENCE 2

ENGAGE

LESSON
7

A DIFFERENT KIND OF STORM

EXPLORE

LESSON
8

WEATHER BEFORE, DURING,
AND AFTER A COLD FRONT

EXPLAIN

LESSON
9

STORMS AND PRECIPITATION
ALONG A FRONT

ELABORATE

LESSON
10

FRONT ON THE MOVE

LESSON
11

A CLOSER LOOK AT LOW
PRESSURE SYSTEMS

A FRONT HEADED YOUR WAY

What other types of storms cause precipitation?



The purpose of this learning sequence is to continue to build students' understanding of the way storms form. In Learning Sequence 1, students examined temperature and humidity data to identify conditions favorable for isolated storms, which form by convection. They developed a model for explaining what happens in the atmosphere that causes an isolated storm. Learning Sequence 2 begins with a discussion of the limitation of the model that they made to describe an isolated storm. Students find that their model does not fit for a storm that they observe in a time-lapse video—the storm lasts longer than an isolated storm. It's a cold front, which is the investigative phenomenon for Learning Sequence 2. Students investigate other ways storms form in a location, specifically when a cold front or low-pressure system moves through a location. Students leverage existing Model Ideas from Learning Sequence 1 and build new ones to explain these new kinds of storms. For example, they apply what they learned in Learning Sequence 1 about rising air leading to clouds and precipitation to understand why warm air, which is pushed upward at a cold front, leads to clouds and precipitation. They test the fit of their new model by revisiting the Colorado storm that they learned about in the Anchor. This sequence shifts spatial and temporal scales, as students move from examining a single location on a single day to examining a larger region across several days.

SCIENCE IDEAS

Air masses are large bodies of air with similar patterns of temperature and moisture. The boundaries between air masses are called fronts. In a cold front, a cooler, drier air mass moves towards a warm, moist air mass. The warm air is pushed upward, which can cause precipitation along the front. Areas where air is moving upward have low pressure. Areas of high pressure are one factor that cause air masses to move. High pressure areas are characterized by air moving downward and spreading out at ground level.

BACKGROUND SCIENCE CONTENT

WHAT IS AN AIR MASS?

Air over a large geographic area with similar temperature and moisture content is called an air mass. For example, the air mass over the Canadian Arctic is cool and dry because it's at high latitude and over land. The air mass over the Gulf of Mexico and Southeast U.S. is warm and moist because it's at lower latitude and mainly over a warm body of water.

FRONTS ARE THE BOUNDARIES BETWEEN AIR MASSES.

There are several different types of fronts including cold fronts (in which a cold air mass moves into a warm air mass), warm fronts (in which a warm air mass moves into a cold air mass), and stationary fronts (in which a cold air mass and warm air mass are moving but not able to push into each other). While this learning sequence provides examples to focus on cold fronts, different types of fronts typically occur together around areas of low pressure.

A cold front forms at the boundary between a cold air mass and a warm air mass when the cold air is pushing into the warm air. Cold fronts can produce dramatic changes in the weather because cold air is so dense it is able to quickly plow into a warm air mass.

Commonly, when the cold front is passing through a location, winds become gusty, and there is a sudden drop in temperature. Heavy rain, hail, thunder, and lightning can happen. The lifted warm air ahead of the front produces cumulus or cumulonimbus clouds. Atmospheric pressure changes from falling to rising at the front. After a cold front moves through, you may notice that the temperature is cooler, the rain has stopped, and cumulus clouds are replaced by stratus or stratocumulus clouds, or clear skies. A cold front (and the cold air mass that moves in) may not be cold but rather "cooler" than the air it is replacing. During the summer, temperatures might be quite warm but a cold front typically brings cooler weather compared with the previous days.

On weather maps, a solid blue line with triangles along it represents a cold front (see image). The triangles are like arrowheads pointing in the direction that the front is moving. Notice on the map that temperatures at ground level are warmer ahead of the front than behind it. This reflects the two different air masses that are meeting at the front. The air mass behind the front is colder than the air mass ahead of the front.

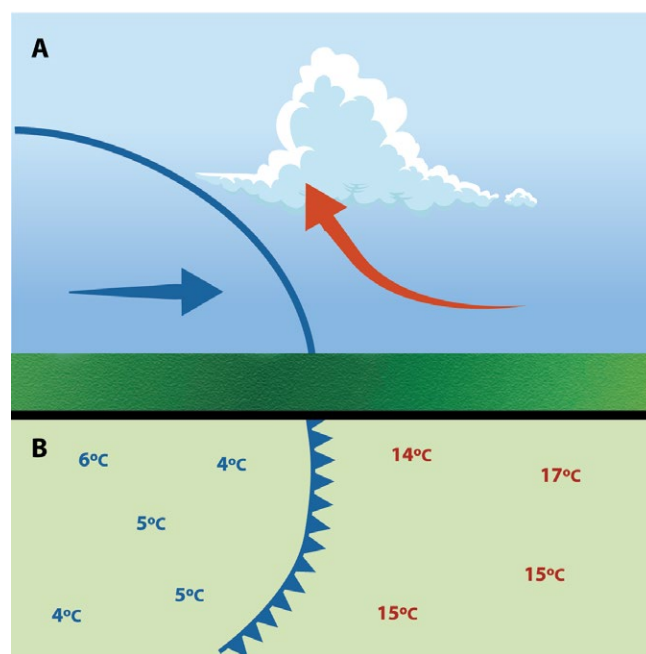
Be on the lookout for student confusion about exactly where precipitation occurs in a cold front. Precipitation happens along a cold front rather than in the air masses themselves because the warm air mass cools and condenses as it moves up higher in the atmosphere.

SPATIAL VARIATIONS IN AIR PRESSURE HELP FRONTS MOVE.

At areas of high pressure (known as "highs" and designated with a capital "H" on weather maps), air from higher altitudes flows downward. At ground level, the downward flow of air spreads out from the high pressure.

At areas of low pressure (known as "lows" and designated with a capital "L" on weather maps), air low in the atmosphere flows upward. At ground level, air rushes in to replace the air that is moving upward.

Overall, surface winds flow from high to low pressure. In the second investigation of this learning sequence, students will learn how differences in atmospheric pressure affect the



A. Cross section of a cold front, where a cold air mass is pushing into a warm air mass. The warm air is pushed upward where it cools and water vapor condenses into clouds.

B. Map view of a cold front. The cold air mass is on the left side, pushing into a warm air mass. The blue line with triangles along it indicates the location where cool and warm air meet.

movement of air masses, creating a cold front as an area of high pressure causes a cold air mass to plow into a warm air mass. (Note: The swirling of air around high and low pressure is due to the Coriolis force, which is covered in Learning Sequence 3.)

Note that while students may grasp that air moves from high to low pressure, they are sometimes challenged to explain why the air is moving. Remind students to think about high pressure forcing air down and low pressure allowing air to rise up. As some air molecules rise, other air molecules move in to fill the space that is left. As some air molecules are pushed downward, the air molecules that were already there are forced to move somewhere else. Drawing and labeling pictures of air moving in high/low pressure systems may be helpful to solidify these concepts.

Fronts and air masses also move because of upper-level movements of the jet stream—the air current at the top of the troposphere that flows from west to east around the planet at the midlatitudes. Because this unit focuses on ground-level weather observations, the jet stream is not included; however, it has an important role in weather. If time allows and if students need an additional challenge, you may wish to include the jet stream in the Explain section of the second investigation.



You can learn more about how different types of fronts form around an area of low pressure by reading the Norwegian Cyclone Model explainer article (NOAA National Weather Service):

[Norwegian Cyclone Model](https://www.noaa.gov/jetstream/synoptic/norwegian-cyclone-model) (<https://www.noaa.gov/jetstream/synoptic/norwegian-cyclone-model>)

COMMON MISCONCEPTIONS:

The following science misconceptions were identified by GLOBE Weather field test teachers. Watch out for them as your students are learning about weather.

MISCONCEPTION	CORRECT EXPLANATION
<p>Cold fronts happen in the winter because it's cold. Warm fronts happen in the summer because it's warm.</p>	<p>Attaching a temperature to a front can be misleading. Fronts happen at all times of the year. The temperature in the name indicates what is happening to the air masses. A front is named after the air mass that moves into another. A cold front forms when a cold air mass pushes into another air mass. A warm front forms where a warm air mass pushes into another.</p>
<p>A warm air mass is as warm as a tropical vacation. A cold air mass is freezing.</p>	<p>The air in a warm air mass can feel quite cool, especially in winter, and the air in a cold air mass can feel warm. The temperature associated with the air mass is relative to adjacent air masses, not an indication of how it feels. Thus, at a cold front in the middle of warm summer weather, a very warm moist air mass may be displaced by a slightly less warm and drier air mass.</p>
<p>Precipitation happens inside an air mass.</p>	<p>Precipitation can happen when there is an isolated storm (as students explored in Learning Sequence 1) within an air mass. But when students are identifying the location of precipitation in the cold front phenomenon explored in Learning Sequence 2, note whether they understand that the rain (or snow) will fall at the front.</p>
<p>Misconceptions about pressure.</p>	<p>In Learning Sequence 2, students will extend their learning about air pressure to include centers of low and high pressure as marked with "L" and "H" on weather maps. Watch for possible misconceptions about pressure including (1) that areas of high pressure are higher in the atmosphere; (2) that where pressure is high, air is rising higher; and (3) that warm air will always be low in pressure.</p>
<p>Warm air holds more humidity because there is more space between molecules.</p>	<p>The space between molecules is not related to the amount of moisture that can be in air. Instead, it is the heat energy of warm air that allows more evaporation, which makes warm air able to have more moisture.</p>



A DIFFERENT KIND OF STORM

What other types of storms cause precipitation?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(30 minutes)	
<p>What's a Cold Front Like?</p> <p>Students share their ideas about types of storms. They view a time-lapse video of a cold front and make observations of this storm. Students then share their initial observations of how a cold front storm differs from the isolated storm they learned about in Learning Sequence 1. Students see an initial forecast for a cold front and make observations of temperature, humidity, and precipitation before, during, and after the front.</p>	<p>Lesson 7: Student Activity Sheet </p> <p>Cold front time-lapse video (https://scied.ucar.edu/weather-timelapse-lyons-colorado-may-8-2017)</p> <p>Whiteboard, smart board, or chart paper and markers (to make the Driving Question Board)</p>



NGSS Sensemaking

In the Engage lesson, students recognize that the model they developed in Learning Sequence 1 is inadequate for explaining some of the observations they have of the Colorado storm. Students notice that the Colorado storm lasts longer than an isolated storm. A new investigative phenomenon is introduced to students: a time-lapse video of a cold front, which is a kind of storm that can last longer and happen at different times of day. Students use existing Model Ideas from Learning Sequence 1 to make predictions about the changing conditions during the cold front and what may be causing those changes.

PERFORMANCE OUTCOME

- Use a model to make predictions about characteristics of air before, during, and after a cold front.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Use a model to predict phenomena.
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Identify limitations of models.

Teacher Procedures

What's a Cold Front Like?

- Navigate from the previous lesson.** Ask students to remind the class of important Model Ideas learned during Learning Sequence 1. Briefly review the Consensus Model students developed for explaining moisture available for an isolated storm. Use the prompts below to guide your discussion.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>What did we figure out about temperature and storms?</i>	Temperature warms up during the day on a sunny day and a stormy day. You need warm temperatures for evaporation.
<i>What did we figure out about humidity and storms?</i>	There has to be humidity in the air for a rainstorm to form.
<i>Can anyone explain why the storm happened in the afternoon?</i>	The storm happens in the afternoon after the Sun warmed the land, which heated the air above the land causing it to rise in the atmosphere and causing clouds to form.

End the discussion:

"We know there are other kinds of storms, and our model only helps us explain precipitation in one kind of storm, so we have some more investigating to do."

- Elicit students' prior knowledge of cold fronts.** Ask students if they've heard of a cold front. If so, what do they know about cold fronts? Just from looking at the term, what would they expect from this kind of a storm? Students may focus on the extreme shift in temperature that happens with a front. Other students may think cold fronts can only happen in the winter. During the Engage lesson, it is okay for students to have incomplete or inaccurate ideas about cold fronts. Take note of what your students know and don't know about cold fronts so that you can return to some of these ideas as this learning sequence unfolds.

LESSON 7
STEP 1

- Make observations of the cold front time-lapse video.** Tell students that you have a video of a cold front, and they need to figure out how this storm is different from the videos they've seen about isolated storms. Tell students they will watch the video twice:
 - The first time students watch the video, have them make observations without taking notes. Discuss their initial observations of how this storm might be different from the isolated storm.
 - Watch the video a second time, and have students take notes in *Lesson 7: Step 1* of their student activity sheets. Focus students on monitoring a certain component of weather and the time of day. You can do this by assigning students a component (e.g., precipitation, cloud cover, cloud types, wind direction) to take notes on and by pausing the video at certain moments to look for evidence of time of day.
 - Have students share what they observed from the video to compile a comprehensive description of observations from the video.



Storyline Link

Have students summarize important Model Ideas they developed in the previous unit. Many of these ideas will carry forward in this learning sequence.



Assessment

Use this opportunity to check for understanding. Listen for accurate explanations about temperature and humidity patterns for an isolated storm. If students are struggling to articulate these ideas, revisit the Model Idea Tracker and Consensus Model for an Isolated Storm.



Developing & Using Models

Learning Sequence 2 is motivated by the limitations of the model developed in Learning Sequence 1. Emphasize to students that models are helpful tools but imperfect.



COLD FRONT TIME-LAPSE VIDEO

Time-lapse video of a cold front from Lyons, Colorado on May 8, 2017

(<https://scied.ucar.edu/weather-timelapse-lyons-colorado-may-8-2017>)

Video break down and time codes:

0:00-0:52 — Sunrise-Noon

0:52-1:26 — Noon-4:00 p.m.

1:26-1:59 — 4:00 p.m.-Sunset

In the video you can see a few high-level cirrus clouds right after sunrise (starting at 20 seconds). Then mid-level clouds, lower and more uniform, form (starting at 27 seconds). Small, low-level cumulus clouds can be seen forming later (around 50 seconds). They grow into a cumulonimbus cloud that starts producing precipitation (about 1 min. 15 seconds). The cumulonimbus clouds change over the rest of the day, sometimes producing precipitation and sometimes not.

You may wish to provide some support for how students make observations from a time-lapse video because the cardinal directions are not given, clouds change so quickly, and precipitation can't be quantified.

- **Wind:** Have students look at the direction that clouds are moving (toward/away from the camera, left or right). Remind students that winds might be moving in different directions at different altitudes.
- **Precipitation:** Pause the video at a point when rain is visible.
- **Clouds:** If students have learned types of clouds, pause the video to give students time to identify the cloud type with ID guides such as the [GLOBE Cloud Chart](http://globe.gov/globecloudchart) (<http://globe.gov/globecloudchart>) or the [UCAR SciEd Field Guide to Clouds](https://scied.ucar.edu/apps/cloud-guide) (<https://scied.ucar.edu/apps/cloud-guide>). Or have students note a general trend in the amount of cloud cover.



For guidance on cloud types see [Observing Cloud Types](#) at GLOBE.gov:



Patterns in Data & Cause-Effect

Students begin to learn the patterns in temperature and humidity data before, during, and after a cold front. They will not be able to recognize this as a pattern until later in the learning sequence.



Storyline Link

Ask students to identify the data we need to understand patterns in a cold front. Students will likely bring up temperature, humidity, and precipitation. They may also mention wind and cloud cover data based on the time-lapse video.

LESSON 7

STEP 1

1. **Ask the question: How is the storm in the time-lapse video different from an isolated storm?** Students should think about the question on their own first. Then discuss as a class and have students record answers on their activity sheet in *Lesson 7: Step 1* (below the video observations box).

Student should notice that, unlike isolated thunderstorms, this storm comes earlier in the day, lasts longer, involves shifts in wind, and involves different cloud types.

LESSON 7

STEP 2

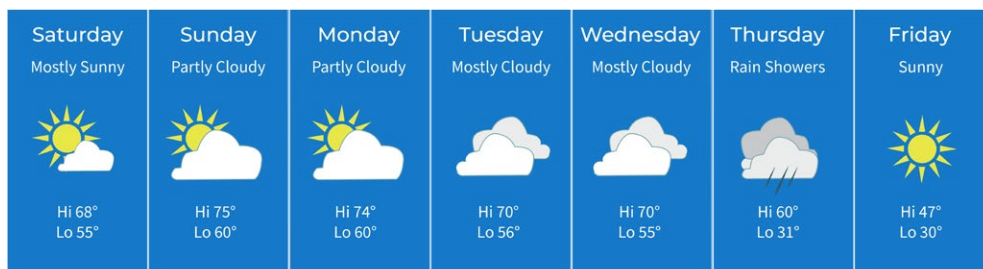
2. **Brainstorm other kinds of storms that don't fit the current model.** Ask students to work in small groups to brainstorm storms they've experienced that are not explained well by the Consensus Model for an Isolated Storm (e.g., thunderstorms at other times of day like the morning or middle of the night, a drizzly rainstorm that lasted all day, a blizzard). Students can record their ideas in *Lesson 7: Step 2*. Have the groups share their ideas aloud. Record important unexplained features of these storms (e.g., time of day doesn't match, the length of the storm doesn't match, the type of precipitation doesn't match).

Use the following questions to elicit student ideas:

- Did the storm happen in the afternoon, like the one in our model?
- Did the storm last a short time (like a few hours), or did it last longer?
- How did the storm change the weather? What was the temperature like before, during, and after the storm?

LESSON
7
STEP 3

3. **Examine a weather forecast of a cold front.** After students note general patterns in a cold front, project a seven-day forecast that includes a cold front. Orient students to the forecast (*What do you notice? What can we tell about the weather?*). You may want to ask your students to make a claim about when the storm front moved through while just looking at the slide of the seven-day forecast before moving on to *Lesson 7: Step 3* of the student activity sheet. Have students share their claims and the evidence from the forecast that supports their claim. Next, hand out the student activity sheets and in *Lesson 7: Step 3* have students identify the day they think the cold front moved through the area. Record the temperatures before and after the cold front. Using information about clouds forming, ask students to estimate whether they think humidity was high or low. (Note that Fahrenheit is used instead of Celsius to match what is common in U.S. weather forecasts.)



4. **Discuss air patterns before and after the front.** Have students use their observations to discuss what the air was like before the front (Sat.-Wed.), what it was like the day the front passed through the area (Thurs.), and what it was like after the front passed (Fri.).
5. **End the discussion with the following question:**
- *What kind of data would be useful to figure out more about this kind of storm?*

Listen for responses such as:

- *We should explore what's different about humidity and temperature in a cold front.*
 - *We should see how much it rained or snowed.*
6. **Provide time for students to update the Driving Question Board.** Students may want to add questions to the Driving Question Board now that they've thought more about cold fronts. Adding questions to the board can be completed as an Exit Ticket or a concluding activity to the Engage lesson.


Assessment

Using Exit Tickets as a formative assessment provides clues to what your students are thinking and where they might need more instruction.

LESSON
8

WEATHER BEFORE, DURING, AND AFTER A COLD FRONT

How is air changing before, during, and after a cold front?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes)	
<p>Data Analysis: Temperature and Humidity in a Cold Front Students examine GLOBE temperature and humidity data for a 10-day period for a cold front that passed through South Riding, Virginia in October 2016. They use patterns from the days before, during, and after the front to characterize what the air was like leading up to the storm and after the storm passes through.</p>	<p>Lesson 8: Student Activity Sheet </p> <p>Whiteboard, smart board, or chart paper and markers (for the Driving Question Board)</p>

LESSON
8

WEATHER BEFORE, DURING, AND AFTER A COLD FRONT

How is air changing before, during, and after a cold front?



NGSS Sensemaking

Students analyze and interpret air temperature and humidity data to figure out how a storm associated with a cold front is similar to, or different from, the convective storm they already investigated. Students identify patterns in atmospheric conditions leading up to the front, during the front, and after the front. They use these patterns to generate a set of Model Ideas that they will use in the next lesson as they develop a Consensus Model for explaining precipitation during a cold front.

PERFORMANCE OUTCOME

- Analyze graphs to describe the changes in temperature and humidity before and after a cold front.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Analyze and interpret data to provide evidence of phenomena and to identify temporal relationships.
- Use graphs to identify patterns in data.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon.
- Patterns of change can be used to make predictions.

Teacher Procedures

Data Analysis: Temperature and Humidity in a Cold Front

1. **Navigate from the previous lesson.** Review the question discussed in the previous lesson to motivate the need to look at data during a cold front:

- *What types of data would be useful to figure out more about this kind of storm?*

Listen for responses such as:

- *We thought it would be important to look at humidity and temperature data during a cold front.*
- *We noticed the wind changing a lot during a cold front.*
- *We wanted to know if the precipitation was a lot and if it rained or snowed.*

Students will begin by examining temperature and humidity data building from their data analysis activities in previous lessons.

2. **Motivate the reason to look at weather data.** Explain that observing a storm in person (i.e., making visual observations, as they did during the Engage lesson) is one way to collect weather data. Using measurements from weather instruments is another way to collect weather data. Ask students to describe the types of measurements they've already found useful for making sense of storms (temperature, humidity).

End with:

Let's see what's going on with temperature and humidity before, during, and after a cold front to see what's similar or different from what we already know.

LESSON
8

STEP 1

3. **Direct students' attention to the Lesson 8: Student Activity Sheet.** Read through the instructions and weather report prompt together. This brief report provides students with useful information to identify when the cold front passed through this location on their graphs.

Prompt students to call out clues from the weather report:

- *What day do we expect the front to move into South Riding, Virginia?*
- *How long do we expect the front to be in the area?*

4. **Preview the new graphs.** Ask students to look at the air temperature graph in *Lesson 8: Step 1* and take note of what's different about this graph compared to the sunny day and stormy day air temperature graphs from Learning Sequence 1 (e.g., now the graph has 10 days and not one day). Consider having students cover up all but one day on the graph to help them notice the connection to the diurnal pattern in the 24-hour temperature graph. Prompt students to notice where the data comes from, how long the data were collected, and other wonderings they have.

Use the following prompts:

- *What information is the graph showing?*
- *Where were the data measured? What time of year?*
- *What do we think the wiggly up and down line means?*
- *How do the ups and downs relate to the temperature ups and downs on our sunny and stormy data graphs?*



Storyline Link

In the previous lesson, students shared ideas about weather data to examine in order to better understand a cold front.



Data Analysis & Interpretation

Students use the I^2 Sensemaking Strategy or comparable graph analysis strategy to analyze temperature and humidity data before, during, and after a front.



Patterns in Data

To support student discussion of the graphs, prompt students to identify patterns in the graphs in terms of before and after the front. The front itself is a disruption to the normal diurnal pattern.

FREEDOM HIGH SCHOOL DATA SET.

This data set comes from Freedom High School (a GLOBE school) in South Riding, Virginia. Data includes the temperature and (relative) humidity from October 16 - 25, 2016. In addition, pressure data from the same location and timeframe is found in Lesson 10. These data come from a WeatherBug automated weather station co-located with this GLOBE school. These automated stations record weather data daily every 15 minutes. These data can be found on the GLOBE Visualization Tool and the GLOBE Advanced Data Access Tool.

5. **Students use the weather report information to circle on the graph when the cold front passes through South Riding, Virginia.** You may also choose to have students label “before,” “during,” and “after,” the front to aid in reading the graph.



6. **Students use the I² Sensemaking Strategy to make observations of the graph and to interpret those observations.** Remind students to make observations before they begin to explain those observations.

- Students write their own What I See (WIS) statements first.
- Have students share their WIS statements in partners or groups. Students can add to their graphs at this time.
- Prompt students to add What It Means (WIM) statements next to each WIS statement. The WIM statements are students' initial explanations of what's happening in a specific part of the graph.
- Ask several students to share their WIS and WIM statements aloud.



STEP 1

7. **Use the questions from the student activity sheet in Lesson 8: Step 1 to guide a discussion about patterns in the graph, focusing on distinctions before, during, and after the front.**

KEY PATTERN: Students should notice a regular diurnal pattern before the front that gets disrupted. This diurnal pattern returns after the front, but it's colder.



STEP 2

STEP 3

8. **Have students circle/label their graphs and use the I² Sensemaking Strategy again as they interpret the humidity graph (Lesson 8: Step 2) and the wind data (Lesson 8: Step 3).** Students will notice changes in humidity before and after the front, which correlate with different air masses. Students will also notice that wind speeds increased as the front moved through. While they may not have all the information to understand the wind data, students should be able to correlate wind with the front.

9. **Conclude the data analysis with a discussion of patterns in atmospheric conditions when the front first arrives on the morning of October 21, 2016:**

- *Why do you think the chances are high for precipitation the morning of October 21?*
- *How is this storm similar to, or different from, the isolated storm?*
- *If you collected weather data at your school, what types of weather events would you likely observe?*

10. **Document Model Ideas to close the lesson.** While students have not developed a model for a cold front yet, now is the time to document Model Ideas (rules of the system) based on their observations of cold front storms—both visual observations from the time-lapse video and data analysis. In this data analysis activity, students learn that humidity is high the morning of precipitation (very much like it was in the isolated storm). This Model Idea should be documented on the Model Idea Tracker.



Developing & Using Models

Use the Model Idea Tracker to document new rules students figured out about a cold front system. Remember these are general rules of thumb that are helpful for explaining a cold front phenomenon. You can consider starting a new Model Idea Tracker for this learning sequence or add to the Model Ideas started in previous lessons.



Going Deeper

Support students in understanding the pros and cons of using a model by debating these ideas in a public setting. Once the Model Ideas are documented, allow students to move around the room between a pro and a con side for each Model Idea. If students think the model did not work to cover the Model Idea, ask them to make suggestions to improve the Model Idea.

Additional Model Ideas you may want to add at this time include:

- Temperatures are warmer before a cold front and follow the normal up/down pattern for a sunny day.
- Temperatures are colder after the front but also follow the normal up/down pattern for a sunny day.
- Humidity is higher before a cold front and follows the normal up/down pattern for a sunny day.
- Humidity is lower after a cold front but also follows the normal up/down pattern for a sunny day.


 LESSON 9

STORMS AND PRECIPITATION ALONG A FRONT

What causes precipitation along a cold front?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(100 minutes)	
<p>Warm Meets Cold</p> <p>Using what students know about atmospheric conditions before and after the front, students make observations of what happens when these two kinds of fluids push into each other. Based on the density tank model, students extract additional Model Ideas to add to the Model Idea Tracker.</p>	<p>Lesson 9: Student Activity Sheet </p> <p>Density tank</p> <p>Warm red water, Cold blue water, Slow-motion video recorder (optional), Colored pencils (red/blue).</p>
<p>Consensus Model: Precipitation along a Cold Front</p> <p>Students use the Model Idea Tracker to start to develop a Consensus Model for explaining why there is moisture available along the boundary between cold and warm air and what happens for precipitation to form. Students read more about air masses and fronts and connect this new information back to the data analysis activity and the density tank. Students revisit their Consensus Models to revise then write an explanation using their models.</p>	<p>Whiteboard, smart board, or chart paper and markers (for the Model Idea Tracker and Consensus Model).</p>
<p>Big Picture: Tracking a Cold Front</p> <p>In this activity, students use their models to explain how precipitation along the front moves as the front moves. This transition is important. Students have looked at one location from a cross-section perspective as a front passes through the location. Now they look at a front from a map-view perspective, following the front as it moves across a region.</p>	<p>Colored pencils.</p>



STORMS AND PRECIPITATION ALONG A FRONT

What causes precipitation along a cold front?



NGSS Sensemaking

Students develop a model for explaining moisture available over a location during a cold front and how that moisture source might lead to precipitation along the front. Students critically read a scientific text to gather more information about air masses and fronts that they can use to refine their Consensus Model. Students switch perspectives to follow a cold front across a region, identifying the location of the front and location of air masses using temperature and precipitation data. Students find that not every location has precipitation, which initiates a discussion of the power and limitation of their Consensus Model.

PERFORMANCE OUTCOME

- Develop a model to show how differences in temperature and humidity before and after a cold front interact to cause a storm.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time and how sudden changes in weather can result when different air masses collide.
- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.
- Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events.

Teacher Procedures

Warm Meets Cold

LESSON 9

STEP 1

- Students review the previous lesson by drawing weather conditions before, during, and after a cold front.** Direct students to *Lesson 9: Step 1* in their student activity sheets. Ask students to draw a visual depiction of atmospheric conditions the day before, during, and the day after a cold front based on what they have learned in the previous activities (e.g., time-lapse video, weather forecast, data analysis from Freedom High School). Prompt students to include in their representations the temperature and humidity conditions based on prior evidence. This activity will help prime students for the density tank demonstration.
- Discuss students' illustrations using the question prompts below:**
 - What days would you expect more rising warm air and why?
 - Would you expect more water vapor to be in the warm air or the cool air?
 - If we looked where the two kinds of air "touched," what would we see?
- Figuring out the air at the front.** Set the stage for this activity: *We need to make observations of what happens where warm and cold air meet to help us figure out why there is precipitation in the area where they meet. Since we can't see air with our eyes, let's use warm and cold water to represent the two air masses to figure out why precipitation forms along the boundary (front).* Set the purpose of the demonstration to figure out why precipitation forms along a front by making observations of a place where cold and warm fluids meet.

DEMONSTRATION: PRECIPITATION ALONG A FRONT

Materials:

- Density tank with a plexiglass divider.
- Warm water (using an electric kettle; do not boil).
- Cold water (chilled with ice, but don't include ice in the tank).
- Red and blue food coloring.



Preparation:

- Heat enough water to fill half the tank using an electric kettle (do not boil) and add red food coloring.
- Prepare a pitcher of cold water chilled with ice (enough to fill half the tank) and add blue food coloring.
- Prepare both warm and cold water outside the density tank and stage them near the tank. Placing the tank in front of a white background (a light colored wall or by hanging white paper behind the tank) will make it easier to observe changes inside the tank.
- With the class watching, add the cold water to the LEFT side of the tank and the warm water to the RIGHT side. You'll need to add both liquids to the tank quickly to avoid too much seepage between the plexiglass divider.



Storyline Link

In this lesson, students learn about a new mechanism for getting warm, moist air high in the atmosphere. Connect to what they already know about convection and isolated storms.



Disciplinary Core Idea: Water

Students work on their conceptual understanding of how moisture becomes available over certain locations and how this differs between a convective storm and a cold front.

- Orient students to the model.** Before adding water to the density tank, show students the model and explain that the tank represents the atmosphere. (You may wish to remind students that a physical model is a representation of a real-world phenomenon.)

Orient students to the parts of the model:

- The bottom of the tank is the land surface.
 - The water in the tank represents air. This model uses water to simulate air because both air and water are fluids, so they behave similarly, but water can be seen.
 - Warm air ahead of the front will be simulated with warm water that is colored red.
 - Cold air behind the front will be simulated with chilled water colored blue.
- Prepare for observations.** Students will sketch a cross section on their student activity sheets after the demonstration. Note that this is the first time a cross-sectional view is introduced and that students may need to be oriented to this perspective (versus a map view). Also note that the water in the demonstration moves very quickly. Students may wish to make a video or take photos. Consider capturing the demonstration using slow-motion video for students to replay to make more detailed observations or by viewing the Density Tank slow-motion video provided below. Explain that having several ways to document what is happening is a good idea because different types of data can be used together to help us understand what is happening.
 - Predict what will happen.** At the start of the demonstration, have a piece of plexiglass dividing the two halves of the tank. Explain how the demonstration will be completed. Ask students to predict what will happen when the barrier is removed.

LESSON
9

STEP 2

- Add water to the tank.** Simultaneously, pour cold water colored blue into the left side and warm water colored red into the right side of the tank. (Note: You can use ice to cool the blue water, but don't include the ice in the tank because it is not a fluid.) Also, do not wait too long before pulling the plexiglass divider as some water may seep around the divider. Students should draw the demonstration set-up before the divider is removed in *Lesson 9: Step 2* of their activity sheets.
- Make observations.** Remove the barrier and have students document what they see happening in the tank in *Lesson 9: Step 2* of their activity sheets. Students should observe that the cold water flows under the warm water, and the warm water is pushed up. (Note: This happens rather quickly in a small tank, so you may wish to have enough warm and cold water on hand to repeat the model a few times.) Review student-captured videos or play the Density Tank slow-motion video several times as needed to assist students as they record their observations.



DENSITY TANK SLOW-MOTION VIDEO

[Slow-motion video of the Density Tank demonstration](https://scied.ucar.edu/cold-front-density-tank-slow-motion)

(<https://scied.ucar.edu/cold-front-density-tank-slow-motion>)

This video shows, in slow motion, what happens when the density tank partition is removed. Notice that the cold fluid (blue) plows into the warm fluid (red), forcing it upward.

- Making sense of the demonstration.** Ask students to share what they observed and articulate how they diagrammed the phenomenon.

Use the following questions to guide this discussion:

- What happened to the warm fluid? What happened to the cold fluid? Why did this happen?
- What would happen to the warm air ahead of the front and the cold air behind the front when they come together?



Developing & Using Models

Explore the power and limitation of models. Students may notice water ricocheting off the side of the tank—an artifact of the model and not part of the process of cold front formation. This is an opportunity to discuss where the density tank model is useful for observing what happens where warm and cold fluids meet, but it also is limited because it's different from the real world.

Use the Model Idea Tracker to document new rules students figured out about a cold front system. Remember these are general rules of thumb that are helpful for explaining a cold front phenomenon.

- How could this help us explain precipitation along the front?

Students should make the analogy to the atmosphere—at a cold front, cold air goes underneath the warm air because it is denser. The warm air goes higher into the atmosphere because it is less dense. Remind students of how isolated storms form where warm, moist air rises higher in the atmosphere. At a cold front, warm, moist air is also pushed higher in the atmosphere, although the mechanism is different.

Students may need support to understand how the warm air is pushed up in this model since the top surface of the water in the tank remains the same. To help students, have them draw a horizontal line on their drawings or photos in the middle of the tank before the divider was removed and after. Note how much of the red (warm) water was below the middle before (half of it) and after (much less than half) the divider was removed.

- 10. Document a new Model Idea on the Model Idea Tracker.** Students figure out that when cold air and warm air meet, cold air flows underneath while warm air rises.

Model Idea:

- When cold air meets warm air, the cold air flows below the warm air. The warm air rises into the atmosphere.

Consensus Model: Precipitation along a Cold Front

- 1. Navigate from the previous activity.** Based on their observations of the density tank, elicit students' initial explanations for why precipitation happens where cold and warm air meet.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>Think back to what we know about air temperature and humidity. Which kind of air is able to evaporate more water? Warm air or cool air?</i>	Temperature warms up during the day on a sunny day and a stormy day. You need warm temperatures for evaporation.
<i>When the warm air rises in the atmosphere, describe what happens to the moisture in the warm air.</i>	When the warm air rises, it gets colder. Cold air can't move as much water vapor into the air, so moisture condenses, forming clouds.



Assessment

Students are ready to put the pieces together to explain precipitation along the front. Students' responses to these questions can inform your approach to the Consensus Model (e.g., do they need more or less scaffolding to put the pieces together)



STEP 3

- 2. Small group Consensus Model.** Explain to students that we need to model how precipitation is happening along the front. Direct students to the list of items to include in their model in *Lesson 9: Step 3* of their student activity sheets. Allow students time to discuss this list in groups to brainstorm their ideas. When they are ready, they can diagram and label their models on their activity sheets as a group. They should discuss how best to represent their ideas in the model. (Note: The model has the air before the front on the right side and the air after the front on the left side. This follows the convention of most cold front models; however, it may be counterintuitive to students because the Freedom High School data for the air before the front was on the left side of the graph and the air after the front was on the right side of the graph. Take time to orient students to the transition between the graphed data and the modeling convention.)

LESSON
9

STEP 4

3. **Readings on air masses and fronts.** Use the scientific reading (*Lesson 9: Step 4*) to clarify and challenge students' models. Orient students to the different weather maps in the reading (*What do the different symbols mean? What information does the map show?*). Set the purpose: *Let's read more about this phenomenon of a cold front to help us clarify a few of the questions we still have. Then we'll come back to our models to make some adjustments.* Students can read individually or as a whole group. Prompt students to stop and think as they encounter questions in the text. These questions are to help students make connections between the information they read and their previous investigations.

LESSON
9

STEP 5

4. **Compare two types of storms.** At the end of the reading (*Lesson 9: Step 5*), students are prompted to diagram two different ways moisture becomes available—the first way is in the isolated storm through convection, and the second way is in a cold front through the interaction of two air masses. These diagrams can inform their models for precipitation along a cold front (*from Lesson 9: Step 3*).

LESSON
9

STEP 3

5. **Revise small group Consensus Models.** Say: *Some things in the reading we already knew, but there was new information we read about. Let's go back to our models (Lesson 9: Step 3) and add details using this new information.* This gives students time to discuss new ideas. As students work, circulate around the room prompting students to add to their models.

Use the following prompts:

- *Where in your model is the warm air mass? Where in your model is the cold air mass?*
 - *How can you use what we observed in the tank to explain what's happening right here where they meet?*
 - *Can you label where there is more moisture and what's happening for it to become precipitation?*
6. **Develop a class Consensus Model.** Ask each group to share their models. As you start to notice patterns in the models (e.g., the warm air ahead of the front is a warm air mass, the warm air mass has more moisture) ask students if they agree we should add this to the Model Idea Tracker. Once several ideas have been added to the Model Idea Tracker, transition to creating the Consensus Model. Decide how to represent each Model Idea in the Consensus Model.

Model Ideas:

- Air masses can have different temperatures (warm, cold).
 - Air masses can have different amounts of moisture (a lot or a little).
 - When a cold air mass pushes into a warm air mass, the warm air moves up above the cold air.
 - As the warm air mass moves up, it cools and moisture in the air condenses, forming clouds, which can lead to precipitation.
7. **Revisit the explanation for South Riding, Virginia (Lesson 9: Step 3).** After the Consensus Model is complete, prompt students to use this model to revise their explanation of the temperature and humidity changes in South Riding, Virginia and why precipitation likely occurred along the cold front. This can be done as a class discussion.

**Obtaining Information**

Students read scientific text to obtain information about a phenomenon in the natural world.

**Literacy Connection**

Students read non-fiction texts and are prompted to make connections and to synthesize ideas.

**Assessment**

Ask students to complete the explanations individually. Evaluate students' explanations as a formative assessment of their understanding of front systems.

Big Picture: Tracking a Cold Front

1. **Navigate from the previous activity.** In the previous activity, students learned that precipitation in a cold front forms along the boundary between cold and warm air masses. Have students explain why the precipitation is located along the boundary using the following prompts:

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>How does the moisture turn into precipitation along the front? What causes that?</i>	The warm, moist air is pushed up by the cold air and the water vapor condenses in the colder temperatures.
<i>What would need to happen for more precipitation to happen or for less to happen?</i>	There would need to be more moisture in the warm air for more precipitation. If there is not a lot of moisture, then there probably wouldn't be as much precipitation.

2. **Talk about perspective.** Up until now, students have explored a cold front looking at a single location as the front moves through. They've developed a model for explaining precipitation along the front but from a cross-sectional perspective. Ask students: *After a front passes through a place, where does it go next?* Tell students that we need to zoom out to see how big the front is, how it travels, and what happens to the precipitation along the front. Zooming out will transition students from a cross-sectional view to a map view, so take time to orient students to what they are examining in this new data set.
3. **Plan for mapping the cold front.** Direct students' attention to *Lesson 9: Step 6* of their student activity sheets. Tell students to use data to locate the front on a map and to identify where and why certain locations have precipitation. Point out that students will be considering how conditions changed over four days at each specific location but also how conditions changed over the four days for the entire region. Let students know that by examining a map view we are able to gain a larger perspective over a region, which is different than the localized cross-sectional views from before.
4. **Read through the instructions together for labeling and coloring their maps.** Break students into groups of four and ensure that each student within the group is assigned a different day to map.
5. **Students map their data and combine their maps for analysis.** Students color and label maps individually. In groups of four, students combine their maps into a four-day sequence. Together, students locate the front and label this on each of the four maps. They use the temperature data to locate and color the cold and warm air masses.
6. **Class discussion and reflection.** Ask students to share their observations of the front moving and the location of the warm and cold air masses. Prompt students to use temperature data to back up their decision about the location of air masses. A second line of discussion should focus on why some locations along the front had precipitation while other locations did not.

Use the following questions to guide this discussion:

- *How can we use temperature to figure out the kind of air over a region?*
- *Where do we think the cold air mass comes from? Why?*



Storyline Link

Students will now use the ideas they've developed to explain a cold front. However, there is an important shift in perspective in this activity (i.e., from cross-sectional view to map view) that may make it more challenging for students. Students may struggle moving from the cross-sectional view of the front to the map view of the front.



Assessment

Use this discussion to formatively assess student learning of fronts and air masses.



Storyline Link

Students will build on the movement of fronts across a region in the next lesson. This conversation can be used to elicit some of their initial ideas.



- *Where do we think the warm air mass comes from? Why?*
- *If we predicted the weather for the next day, which direction would the front move?*
- *Let's use our model to figure out why some locations along the front had precipitation while others did not.*

POWER AND LIMITATION OF MODELS: WEATHER PREDICTIONS.

The last question in the set above might lead to a discussion of students' models for explaining precipitation along a cold front. Not all locations along the front have precipitation, so students should consider how their models help them figure out what's happening in the places with precipitation and what might be happening where there is no precipitation. Students may identify that their models are limited—there must be other factors that control the amount of precipitation that their models do not take into account. It's important to talk about how their models are helpful for understanding precipitation along a cold front and where their models might be incomplete.

**Developing & Using Models**

Students think about the lack of precipitation in locations to reflect on the limitations of their Consensus Model.


 LESSON 10

FRONT ON THE MOVE

What causes fronts to move?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(100 minutes before optional extension)	
<p>Under Pressure (50 min.) Students are introduced to air pressure and its role in the movement of air masses and fronts. Students analyze air pressure data to identify areas of high and low pressure around a front. They use this information to identify patterns in areas of high and low pressure and to generate a reason fronts move from high to low pressure.</p>	<p>Lesson 10: Student Activity Sheet </p> <p>Colored pencils (red/blue). Balloons, dry beans, lentils, or small beads. Paper and pencil.</p>
<p>Optional Extension: Barometric Pressure Measurements Students use the GLOBE Barometric Pressure Protocol to make measurements of barometric pressure.</p>	<p>Aneroid barometer or altimeter GLOBE Barometric Pressure Protocol (globe.gov/do-globe/globe-teachers-guide/atmosphere)</p>
<p>Pressure: Data Analysis (50 min.) Students examine pressure and wind data for South Riding, Virginia and continue to develop their ideas about high and low pressure before, during, and after a front. Students add to their Model Idea Tracker and revisit their Consensus Model.</p>	<p>Whiteboard, smart board, or chart paper and markers (for the Model Idea Tracker and Consensus Model)</p>



FRONT ON THE MOVE

What causes fronts to move?



NGSS Sensemaking

In the first Elaborate lesson, students begin to explain movement of air masses and fronts by scaling up ideas about air pressure as they pertain to high- and low-pressure systems. Students begin their investigations by revisiting South Riding, Virginia data, now layering on air pressure before, during, and after the front.

PERFORMANCE OUTCOME

- Analyze patterns in data to describe how pressure changes before and after a cold front.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Analyze and interpret data to provide evidence of phenomena and to identify temporal relationships.
- Use graphs to identify patterns in data.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon.
- Patterns of change can be used to make predictions.

Teacher Procedures

Under Pressure

1. **Navigate from the previous lesson.** Using students' ideas from the Big Picture activity (*Lesson 9: Step 6*), review the following questions from the previous discussion:

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>If we predicted the weather the next day, which direction would the front move?</i>	The front would probably move to the right because we saw that in the Big Picture.
<i>What do we think is causing the front?</i>	The wind is causing the front.

2. **Set the purpose for this activity.**

Explain to students:

Now that we know more about how a front works, let's see if we can figure out why it's moving and where it's headed next. If we can figure this out, we know which communities should expect precipitation from the front when it arrives in their areas.

3. **Remind students about air pressure by physically modeling air pressure.** *Tell students that barometric pressure measurements are another weather measurement needed to figure out the direction of movement. Use beans or an equivalent item (lentils, beads, etc.) to have students model what air at high pressure might feel like compared to air at low pressure. Give students 20 beans to hold in one hand compared to five beans in the other hand. Have students close their eyes and pay attention to the pressure the beans are putting on the surface of their hands. (Note: The beans do not do a good job modeling the distance between the grains and whether the air is rising or sinking in the column. However, it can be used to help students understand that what's in the column of air above a surface exerts pressure onto that surface.)*
4. **Optional extension: Measure barometric pressure using the GLOBE Barometric Pressure Protocol.** The GLOBE Barometric Pressure Protocol is another excellent opportunity for students to make measurements of their environment and to provide experience with barometers as tools for measuring the weather. Introduce the GLOBE Barometric Pressure Protocol at this time if students will be making measurements. You will use an aneroid barometer or altimeter along with the protocol. If you have a digital barometer in your classroom or any other equipment for measuring barometric pressure, it would be valuable to take readings from those as well.



[The Barometric Pressure Protocol](https://www.globe.gov/do-globe/globe-teachers-guide/atmosphere)

(<https://www.globe.gov/do-globe/globe-teachers-guide/atmosphere>)

LESSON
10

STEP 1

5. **Connect air pressure to rising and sinking air.** Direct students' attention to *Lesson 10: Step 1* of their student activity sheets. Have students read the page and then, as a class, discuss the image (below) that shows how air moves in areas of high and low pressure. Ask students to think about how the density of the sinking air in an area of high pressure is different than the density of the rising air in a low-pressure area. Point out that a large, blue "H" is used on a weather map to indicate the center of high pressure, and a large, red "L" is used to indicate the center of low pressure. (Note: It's okay if students do not know why air turns in different ways for high and low pressure. This can be revisited again after the Coriolis effect is taught in Learning Sequence 3.)



Storyline Link

Students continue to build an understanding of the movement of a cold front through a region, adding in the role of areas of low and high pressure.



Disciplinary Core Idea: Air Pressure

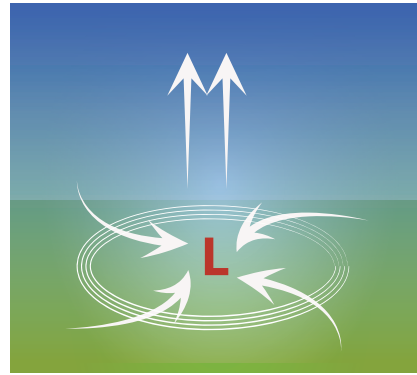
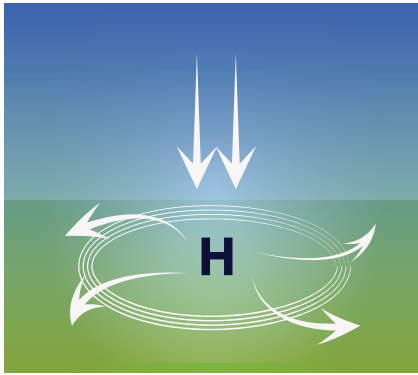
The content of this activity depends on whether your students have learned about air pressure prior to this unit. If so, leverage what they know to explore air pressure in more depth. The current version of the activity is written without this expectation.



GLOBE Connection

GLOBE schools also collect barometric pressure data. If your students are familiar with making the measurement, help them make the connection between the data they collect and the data they are investigating.

LESSON
10
STEP 1



6. **Connect the vertical up and down movement of air pressure with the horizontal toward and away movement.** Using the same graphic, transition to focusing on the arrows moving toward the area of low pressure and the arrows moving away from the area of high pressure.
7. **Make a hands-on connection to air movement in high and low pressure.** Break students into pairs. Give each pair a balloon filled with a golf-ball-sized amount of dry beans (or lentils, beads, etc.). Tell students that the beans inside the balloon represent molecules of air. They are to place their balloon on a piece of paper and trace a circle around the edges of their balloon. Have one student push down on the balloon, simulating high pressure. The other student should trace a new circle around the edges of the “pressurized” balloon. Next simulate low pressure by releasing the balloon. Compare the size of the two circles. Students can take turns simulating high pressure on the balloon and low pressure by releasing the balloon.

Students should take turns explaining to each other what happens to air under high pressure and low pressure, using the following prompts:

- *What happens to air when there is high pressure? Where does it go?*
- *The circles you drew show how air moved at the ground level. Why was the circle bigger for the air under high pressure?*

Refer to the diagrams in *Lesson 10: Step 1* to help students make connections between air in the atmosphere and the balloon activity.

8. **Demonstrate our understanding of air under high pressure and low pressure.** Consider using a back-to-back strategy here to get students up and moving as they discuss their ideas. Students reflect on how the up and down movement of air influences the movement of air across the surface.
- Form two lines, standing back-to-back with a person from the other line.
 - Listen to the question the teacher asks related to the activity:
 - *If air at an area of low pressure is rising, why would these arrows move toward it?*
 - *If air at an area of high pressure is sinking, why would these other arrows move away from it?*
 - Ask students to individually reflect until the teacher calls: Turn (usually about 30 seconds). Then say: *Turn.*
 - Students discuss their reflections with the student with whom they were back-to-back.



Data Analysis & Interpretation

Students analyze barometric pressure data around the front from the Big Picture.



Using Models

Using the filled balloon to simulate air in high- and low-pressure systems provides a kinesthetic connection to the concepts.



Going Deeper

Blow up a balloon. Sketch what high pressure inside the balloon looks like compared to the low pressure outside the balloon. Ask students to predict what would happen if you popped the balloon. Would air rush in or would the air inside rush out? Ask students to diagram the direction the air would move (from high pressure inside to low pressure outside). Then pop the balloon!

9. **Use pressure data to figure out which direction a front is moving.** Direct students to *Lesson 10: Step 2* of their student activity sheets. Read through the instructions together and orient students to the air pressure map.

LESSON
10
STEP 2

10. **Ask students to make predictions:** *If areas of high pressure and low pressure were in the same region, how would you predict air to move between the two of them?* Then give students time to complete the activity.
11. **Discuss the patterns students see and how air pressure relates to movement.** Keep the columns of cold air and warm air projected for students. Using the discussion prompt at the bottom of the student activity sheet, facilitate a discussion where students generate a claim about which way the wind blew. Students will continue to develop this explanation in the next activity.

Suggested question to discuss:

- *The front is moving from the west (left side of the map) to the east (right side of the map). The arrows on the cold front point in the direction it is moving. Using the barometric pressure measurements, why might the front move in this direction?*

PRESSURE: DATA ANALYSIS

1. **Navigate from the previous activity.** Students started to develop an explanation for pressure by examining barometric pressure readings around a front. Have students review what they learned from this activity focusing on where high pressure was located (behind the front) and where low pressure was located (along the front and at the northern end).
2. **Set the purpose for looking closer at pressure.**

Ask students:

If we go back to Freedom High School in Virginia and were expecting a cold front to come through, how would we expect pressure to change before, during, and after the front?

Tell students to use what they learned from the previous lesson (*Lesson 10: Steps 1 & 2: Under Pressure*) to predict what the pressure might be like as the front moves through a location. Elicit students' initial ideas in response to this question.

LESSON
10
STEP 3

3. **Direct students to Lesson 10: Step 3 on their activity sheets.** Read through the instructions together. Prompt students to use the I² Sensemaking Strategy (What I See/What It Means) to analyze the barometric pressure graph. Remind students that they are now looking at a single location as the front moves through. Orient students to the graphed data as needed before they analyze the graph.
4. Students analyze and interpret the graph. Give students time to work together to analyze the barometric pressure graph. Prompt students to discuss and then answer the analysis questions below the graph.
5. **Discuss the data to generate Model Ideas.** Discuss students' observations of the graph. Focus students on sharing What I See statements first before transitioning to What It Means statements. As students share observations of low pressure and high pressure, ask them to make connections to the pressure regional map (*Step 2*) and where the areas of low and high pressure occurred around the front (e.g., near the front, behind the front).



Assessment

Listen to how students explain their thinking to their partner as a formative assessment.



Data Analysis & Interpretation

Students analyze pressure data from Freedom High School to identify where the low and high pressure is located around a cold front.



Storyline Link

Students viewed pressure data from a map perspective across a region. They will now view pressure data for a single location across time. Make this shift in perspective explicit to students.

Generate patterns to explain pressure and turn these patterns into Model Ideas for the Model Idea Tracker.

- **Model Ideas rooted in the spatial, map view data may be:**
 - Areas of high pressure are usually behind the cold front.
 - Areas of low pressure are around the front and at the northern end.
- **Model Ideas rooted in the analysis of temporal data may be:**
 - After a cold front moves through, a location may experience high pressure associated with cooler, sinking air that has less moisture.
 - Just before and during the storm, an area may experience low pressure, which is associated with warm, rising air and precipitation.
 - Air moves from high to low pressure.

**Developing & Using Models**

Add to the Model Idea Tracker new ideas about areas of high and low pressure and how air is moving between the two.



A CLOSER LOOK AT LOW-PRESSURE SYSTEMS

What could cause a front to stall?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(75 minutes)	
<p>Explaining the Colorado Storm</p> <p>Students revisit the Colorado storm from the Anchoring Phenomenon (Lesson 1), examining rainfall data and interpreting a storm report to develop an initial model of the storm. Students use their models to develop a Consensus Model to describe how exceptional moisture from the Gulf of Mexico and Pacific Ocean made its way to Colorado (e.g., through the interaction of air masses along a stalled front and influences of areas of high and low pressure on the movement of the front).</p>	<p>Lesson 11: Student Activity Sheet </p> <p>Video from the Anchoring Phenomenon (Lesson 1).</p> <p>Whiteboard, smart board, or chart paper and markers (for the Model Idea Tracker, Consensus Model, and Driving Question Board).</p> <p>Video of storm water vapor.</p> <p>NASA videos showing storm movement across the U.S.</p>



A CLOSER LOOK AT LOW-PRESSURE SYSTEMS

What could cause a front to stall?



NGSS Sensemaking

Students use general Model Ideas to develop a case-based model for the Anchoring Phenomenon. Students analyze rainfall data and interpret a weather report to piece together the major factors that caused the Colorado storm in 2013. They use their knowledge of air masses, fronts, and areas of high and low pressure to explain why Boulder and the surrounding region received exceptional precipitation. Students identify Model Ideas that are useful for explaining a wide variety of storm phenomena and also the case-specific things happening in the Colorado storm that made it unique.

PERFORMANCE OUTCOME

- Analyze pressure and humidity data to describe the movement of air and moisture from one place to another.
- Develop a model to show how differences in pressure cause the movement of moisture that leads to a storm.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.
- Analyze and interpret data to provide evidence of phenomena and to identify temporal relationships.
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (3-5) (REINFORCING)

- Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon.
- Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequently and regularly occurring events.
- Patterns of change can be used to make predictions.

Teacher Procedures

Explaining the Colorado Storm

- Navigate from the previous lesson.** Have students summarize the ideas added to the Model Idea Tracker from the previous lesson. Consider doing this by asking students to stop and jot down big ideas they learned in the previous lesson. Use the discussion of these ideas to help you assess what big points students took away from the previous pressure activities.

 - Model Ideas rooted in the spatial, map view data may be:**

 - Areas of high pressure are usually behind the cold front.
 - Areas of low pressure are around the front and at the northern end.
 - Model Ideas rooted in the analysis of temporal data may be:**

 - After a cold front moves through, a location may experience high pressure associated with cooler, sinking air that has less moisture.
 - Just before and during the storm, an area may experience low pressure, which is associated with warm, rising air and precipitation.
 - Air moves from high to low pressure.
- Revisit the Anchoring Phenomenon.** Set the stage for using these models to figure out what's happening with the Colorado storm. Replay the video.



CASE STUDY: COLORADO FLOODS

In September 2013, a storm stalled over the region around Boulder, Colorado bringing a weeklong deluge of rain, resulting in dangerous floods.

[How the City's Resilience Strategy Saved It](https://scied.ucar.edu/video/boulder-colorado-flood-how-citys-resilience-strategy-saved-it)

(<https://scied.ucar.edu/video/boulder-colorado-flood-how-citys-resilience-strategy-saved-it>)

[What Flooding Looked Like in Boulder, Colorado](https://scied.ucar.edu/boulder-floods) (<https://scied.ucar.edu/boulder-floods>)

The video is six minutes, 48 seconds in length and provides a case study. To help students focus on what happened in the flood, note the following time codes:

0:00-2:08—Introduction to the 2013 flood in Boulder and past floods in this same area. Some effects are shown.

2:09-4:11—Engineering considerations related to managing future floods based on past experiences are addressed.

4:12—End of video on the 2013 flood and community resilience.

6:13—A cause is mentioned.

- Explain that the Colorado storm was unusual.** Explain to students that this storm was different from an isolated storm and a cold front. Tell students that their job is to examine data from the Colorado storm and compare it with what they know about typical isolated storms and cold fronts.



Assessment

Ask students to jot down some of the big ideas we came up with in the last lesson. Listen to the ideas that students share and how closely they match the Model Ideas added to the Model Idea Tracker on the previous day. This provides useful information about how close individual student's main takeaway ideas match the Model Ideas developed collaboratively by the class.

LESSON
11
STEP 1

4. **Students analyze rainfall data from the Colorado storm to learn how long it lasted.** Read the instructions at the top of the *Lesson 11: Student Activity Sheet* together. Arrange students in groups to do an analysis activity in *Lesson 11: Step 1*. After examining the rainfall data, students make a claim about whether the Colorado storm was an isolated storm, a cold front, or something different. Students should use evidence from throughout the unit to support their claim. Use a show of hands to see which claims the students initially support.
5. **Ask students to think about how the Colorado storm is different from other storms they have learned about.** This storm is different from isolated storms and typical cold fronts because of the length of time it rained and the lack of movement (stalling).

LESSON
11
STEP 2

6. **Students determine important factors in the storm.** Students read a storm report (*Lesson 11: Step 2*) to collect information about why the storm stalled and lingered over one area for so long. Guide students to use what they have learned about how areas of high pressure can push air masses. Cue students to consider the balloon model we used in Lesson 10 as they think about how air pressure could stall a front. In the case of the Colorado storm, areas of high pressure boxed in the front, so it couldn't move, which is why so much rain fell.
7. **Have students construct a Consensus Model for the Colorado storm in small groups.** Tell students to use the weather report to create a model on the map (*Lesson 11: Step 2*) showing the different forces at play in the Colorado storm. They should label where high pressure and low pressure are located, the front, and the air masses involved as well as where the moisture is coming from.

LESSON
11
STEP 3

8. **Develop a whole group Consensus Model.** Have small groups present their models to the class. As each small group presents, prompt students to ask questions about each other's models. Note areas where groups seem to agree on what's happening, and also note areas of differences. After all groups present their models, transition to developing a class Consensus Model. This model should reflect agreed upon ideas. Start with ideas that students agree on before moving to areas of disagreement or incomplete ideas. Students should use the model to answer the questions in *Lesson 11: Step 3* about the Colorado storm.
9. **Reflect on the new model.** After students build the new model, prompt them to think about what this new model helps to explain that the other models could not explain. Remind students that the Colorado storm was an unusual storm with all these unique variables. Look at the Consensus Model and identify a few underlying, general Model Ideas that would happen in most storms and a few unique, case-based ideas that happened in the Colorado storm specifically.

General Model Ideas:

- A warm, moist air mass got pushed up by a cooler air mass.
- Low pressure was pulling air toward it.
- High pressure was pushing air away from it.

Specific Model Ideas—Colorado storm:

- Three areas of high pressure “trapped” the front and it stalled.
- The low pressure kept pulling in moisture from the Gulf of Mexico and Pacific Ocean.

Power and limitation of models: Discuss how some Model Ideas can be useful for explaining parts of a storm but how there are also unique things that could be happening in any one storm that make it more difficult to predict.



Developing & Using Models

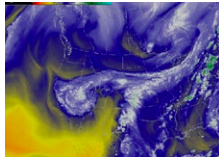
Students create an initial draft of the Colorado storm model that they will use for constructing the Consensus Model. As students work in groups, they do not need to agree upon all parts of the model. They should bring their disagreements and uncertainty to the Consensus Model discussion. Have the Model Idea Tracker and evidence from previous cold front and air pressure activities ready to revisit during the consensus discussion to help resolve disagreements.



Storyline Link

To motivate the need for further investigation in Learning Sequence 3, scale out from the storm and watch it using satellite imagery of the water vapor in the atmosphere. There's a lot of vapor traveling long distances and in somewhat predictable ways. Take it one step further to look at regional patterns in how storms move across large areas. Ask students to think about the direction of these storms and whether they notice patterns in the movement (west to east). Explain to students that we still need to investigate why storms tend to move in certain directions and how moisture travels over long distances.

- 10. Revisit the Driving Question Board.** Give students time to revisit questions on the Driving Question Board. Students should share and explain questions they now feel they can answer. Students can also share new questions they may have about storms.
- 11. Motivate Learning Sequence 3.** Look at satellite imagery for the Colorado storm to get students thinking about large-scale patterns. Ask students what they notice about the way air was moving across the U.S. when the Colorado storm happened.



SATELLITE IMAGERY: COLORADO FLOODS

This satellite imagery shows water vapor over the U.S. during September 11-12, 2013.

[The 2013 Boulder Flood](#)

<https://www.bouldercast.com/the-2013-boulder-flood-two-years-and-three-billion-dollars-later/>

- 12. Broaden from Colorado to another region.** Choose one of the NASA videos below to preview with students. Use the video to notice patterns in the way air and storms move across the U.S. Ask students to identify the direction the storm moves and where the moisture for the storm could come from. This will help you set the stage for student learning in Learning Sequence 3 as they dive into latitudinal patterns of heating, precipitation, and prevailing winds.

SATELLITE IMAGERY: NASA IMAGERY OF STORMS IN THE UNITED STATES

These videos capture storms in the U.S. in different regions in 2016 and 2017. The imagery is made by NOAA's GOES-East satellite (NASA/NOAA GOES Project). Select a region that might be most interesting for your students, or if time permits, view all three videos to notice similar and different patterns.



Option 1: [NASA Sees Severe Weather from Central to Eastern US](#)

(<https://www.youtube.com/watch?v=V-euF5ScXbY>)

Dates: April 29-May 1, 2017



Option 2: [Major Winter Storm Nearing Mid-Atlantic Region](#)

(<https://www.youtube.com/watch?v=awVjB2VQxdU>)

Dates: January 20-22, 2016



Option 3: [Southern California and U.S. West Coast Storms](#)

(<https://www.youtube.com/watch?v=estSuHF3Vwk>)

Dates: January 5-7, 2016

- 13. Assess student learning with the Learning Sequence 2 assessment.** You can find the assessment item bank and rubric in the Assessments section of *GLOBE Weather*.



Assessment

See the GLOBE Weather Assessments section for the Learning Sequence 2 assessment.



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TEACHER GUIDE

TEACHER GUIDE



LEARNING SEQUENCE 3

ENGAGE

LESSON
12

STORMS ON THE MOVE

EXPLORE

LESSON
13

HEATING UP

EXPLAIN

LESSON
14

AIR MOVEMENT IN THE TROPICS

ELABORATE

LESSON
15

A CURVEBALL

Worldwide Weather

Why do storms move in predictable patterns around the world?



The purpose of this learning sequence is for students to figure out why storms move the way they do, on a global scale. While the weather can change day-to-day, the investigative phenomenon anchoring this learning sequence is that prevailing winds at different latitudes move moisture in predictable patterns. Students investigate how solar radiation leads to uneven heating of the atmosphere. Students leverage existing Model Ideas from Learning Sequence 1 and new ideas about solar radiation to explain how this uneven heating causes convection on a global scale. They develop a model to explain air movement in the tropics and test their models to see if they can explain precipitation movement patterns near the equator. Students realize their current models only explain the north to south movement of winds. They read and develop understandings about how the Coriolis effect causes winds to curve, accounting for the east to west movement near the equator. Students can then predict the directions storms would travel in various locations around the world. This sequence shifts the spatial scales and focus, as students move from examining what causes storms to form over several days across a region to explaining why storms move in predictable patterns around the world.

SCIENCE IDEAS

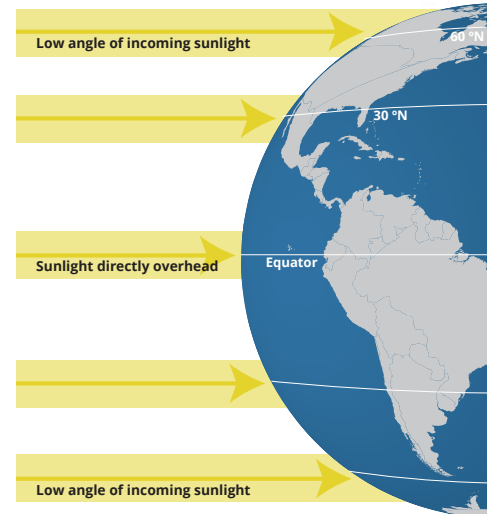
Concentrated sunlight heats the Earth more at the equator than at the poles. This causes warm, moist air to rise near the equator, creating areas of low pressure that lead to clouds and rainfall, releasing water vapor and cooling the air. This air cools more as it is forced away from the equator, sinks at 30° N and 30° S and is pulled toward the low pressure area at the equator to replace the rising air. This is convection on a global scale. The Earth's rotation creates three areas of circulation in each hemisphere. In the tropics, winds move across Earth's surface toward the equator—prevailing winds known as the trade winds. The Earth's rotation causes prevailing winds to curve due to the Coriolis effect. In the tropics, prevailing winds move from east to west. In the midlatitudes, they move from west to east, leading to predictable patterns of storm movement around the world.

Background Science Content

THE SUN'S ENERGY AND LATITUDE

The Sun's energy heats the Earth's surface unevenly. Latitudes at or near the equator are warmer overall than places that are far from the equator (towards the North and South Poles), which receive less sunlight per unit of area. This is because the Sun is most directly overhead and most intense near the equator and lower in the sky at higher latitudes where the same amount of energy is spread out over a larger area. As you listen to student ideas about why it is warmer near the equator, note that some students might think that temperatures are warmer near the equator because those places are "closer to Sun," and temperatures are cooler in the midlatitudes because those places are "farther from the equator and therefore farther from the Sun."

Additionally, locations far from the equator have strong seasonal differences in temperature, and locations at or near the equator have little or no seasonal differences in temperature (aside from that caused by storms or other weather phenomena). This occurs because Earth's axis is tilted, so a location far from the equator receives more sunlight at times of year when its hemisphere is tilted towards the Sun and less sunlight at times of year when its hemisphere is tilted away from the Sun.

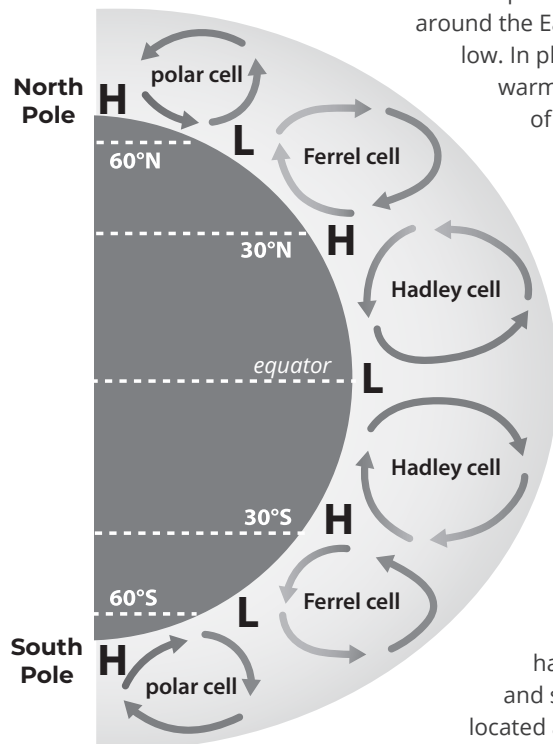


Incoming sunlight at various latitudes
(Credit: SA Geography)

These variations with latitude are explored in Lesson 13, in which students interpret data that shows general differences in temperature between Earth's poles and the equator.

GLOBAL ATMOSPHERIC CIRCULATION

While weather can change day-to-day, surface winds at different latitudes move in predictable ways. These surface winds are part of a pattern of global atmospheric circulation, which is the result of the Sun heating the Earth more at the equator than at the poles (because there are differences in air temperature around the Earth, the air circulates). In places where warm air is rising, air pressure is low. In places where cool air is sinking, air pressure is high. The systematic rising of warm air and sinking of cool air is called convection and describes the circulation of air in predictable patterns, or circulation cells, around the Earth. There are three circulation cells in each hemisphere: the Hadley cell, Ferrel cell, and polar cell as shown in the image.



The Hadley cells are located between the equator and 30° north and south of the equator. At the equator, warm, moist air rises, creating areas of low pressure that leads to clouds and rainfall, releasing water vapor as air rises to the top of the troposphere (the tropopause). The air, now cooler, is forced north and south of the equator, and it cools even more. At 30° north and south of the equator, the cooler, drier air sinks towards the ground creating high pressure. Some of the sinking air travels to higher latitudes, forming the Ferrel cell, and rises at about 60° north and south latitude. Some of that rising air moves towards the poles then sinks as part of the polar cell.

High pressure areas are found at 30° north and south. These latitudes have stable weather (warm/dry). Many deserts are located near 30° north and south where high pressure areas are located. Low pressure areas are located at the equator and at 50°-60° north and south and have unstable weather (more clouds and precipitation). In the midlatitudes and at the equator, there is more precipitation especially along the west coast of continents associated with low pressure areas.

THE CORIOLIS EFFECT

Global atmospheric circulation is also affected by the spin of the Earth. The Earth spins from west to east on its axis. Because the Earth is widest at the equator, it rotates faster at the equator than at the poles, and surface winds (or objects) are deflected, or turned, by the Coriolis effect.

The Coriolis effect is zero at the equator and then increases in magnitude towards the poles. The Coriolis effect is the apparent acceleration of a moving body as a result of the Earth's rotation (deflecting the direction of the north-south air). If the Earth didn't spin, there would be just one large convection cell between the equator and poles. The deflecting winds split the one cell into three convection cells.

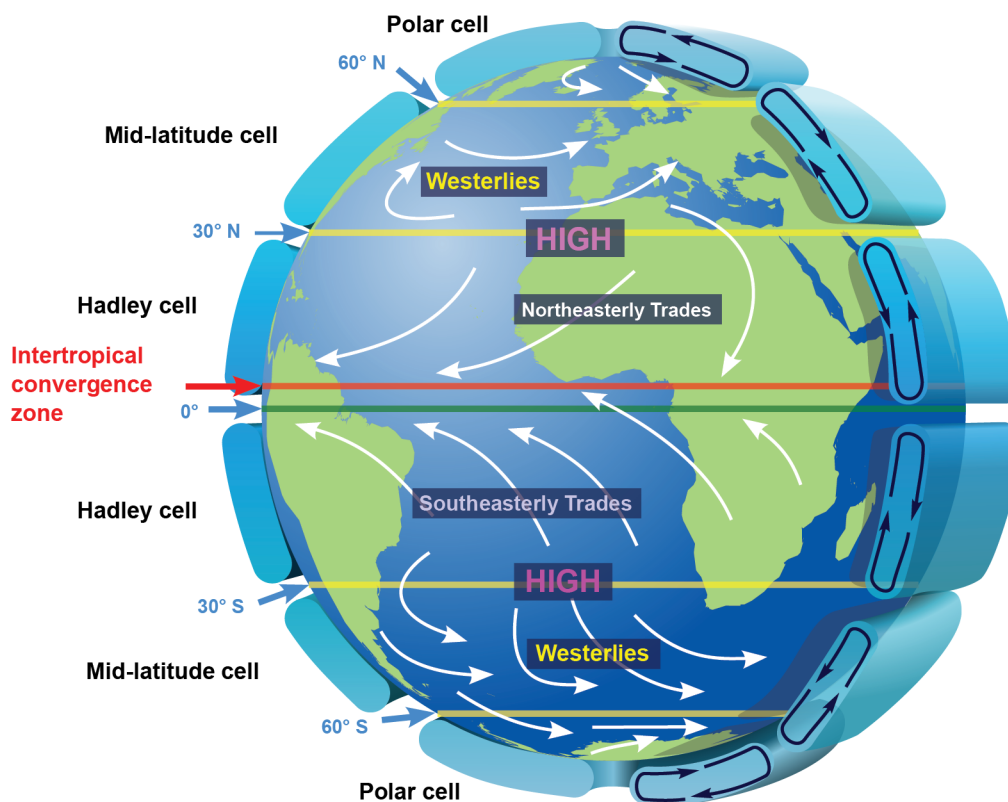


- The [NOAA Scijinks website](https://scijinks.gov/coriolis/) (<https://scijinks.gov/coriolis/>) provides an explanation about the Coriolis effect that may be helpful for students.

The Coriolis effect greatly impacts the prevailing wind direction on a global scale (see image below).

The prevailing winds at the Earth's surface, caused by convection, are deflected by Earth's rotation, causing them to curve to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The (surface) trade winds in the tropics are associated with the Hadley cells and move towards the equator, southwest in the Northern Hemisphere and northwest in the Southern Hemisphere. In the midlatitudes, where the Ferrel cells are located, warmer surface air moving poleward is deflected east by the Coriolis effect, which leads to prevailing westerly surface winds (west to east) in both hemispheres. At the higher latitudes, where the polar cells are located, the prevailing surface winds are easterly (east to west) in both hemispheres.

In addition, on a smaller scale, air moving toward an area of low pressure and away from high pressure is also influenced by the Coriolis effect. Air moves counterclockwise around low pressure in the Northern Hemisphere and clockwise around low pressure in the Southern Hemisphere. This is why storms in the Northern Hemisphere rotate counterclockwise, while storms in the Southern Hemisphere rotate clockwise.



Credit: Kaidor
creativecommons.org/licenses/by-sa/3.0

COMMON MISCONCEPTIONS:

The following science misconceptions were identified by *GLOBE Weather* field test teachers. Watch out for them as your students are learning about weather.

MISCONCEPTION	CORRECT EXPLANATION
<p>It is warmer at the equator because it is closer to the Sun.</p>	<p>While it is true that the Earth “bulges” at the equator, there is no significant difference in the distance to the Sun, whether measuring from the equator or from the poles. The reasoning for warmer temperatures at the equator is because of the angle of the Sun; at the equator the Sun is directly overhead, providing more heat, while areas further from the equator receive less direct sunlight and thus less heat.</p> <p>For more information, visit: Seasons and Why the Equator is Warmer than the Poles (https://serc.carleton.edu/sp/library/guided_discovery/examples/seasons.html)</p>
<p>Summer occurs when the Earth is closest to the Sun and winter when the Earth is farthest from the Sun.</p>	<p>Similar to the reasoning in the misconception above, it is not the distance between the Sun and the Earth that causes the extreme changes in latitudinal and seasonal temperatures (In fact, the Earth is closest to the Sun in January, which is winter for the Northern Hemisphere, and farthest from the Sun in July, when the Northern Hemisphere is experiencing summer). The reason for the seasons is the 23.5° tilt of the Earth on its axis, which means that each hemisphere experiences warm seasons when it is pointed more directly at the Sun and cold seasons when it is pointed away from the Sun.</p> <p>For more information, visit: What Causes the Seasons? (https://spaceplace.nasa.gov/seasons/en/)</p>
<p>Heat from the Earth’s core is responsible for heat at the Earth’s surface.</p>	<p>While it is true that the Earth’s core and mantle are extremely hot (the source of this heat is the decaying of radioactive elements within the Earth as well as residual heat from when the Earth formed), as students discovered in Learning Sequence 1, Earth’s surface temperature is a result of incoming radiation from the Sun. The amount of heat energy flowing to the surface from the Earth’s interior is only about 1/10,000th of the amount of energy flow from the Sun to the Earth’s surface.</p> <p>For more information, visit: Heat from the Earth’s interior does not control climate (https://www.skepticalscience.com/heatflow.html)</p>

LESSON
12

STORMS ON THE MOVE

How do storms move around the world?

ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes)	
<p>Global Precipitation Patterns Students watch a video and record observations of precipitation movement patterns first in North America and then globally. They share observed patterns and generate questions in small groups, followed by a whole class discussion. Students add new questions to the Driving Question Board.</p>	<p>Lesson 12: Student Activity Sheet <small>LESSON 12</small> North America storm movement time-lapse video NASA rainfall and snowfall video Whiteboard, smart board, or chart paper and markers (to make the Driving Question Board)</p>
<p>Develop Initial Explanations Students develop initial ideas to explain these patterns in global precipitation movement, drawing on prior experience and Model Ideas from Learning Sequences 1 and 2.</p>	

LESSON
12

STORMS ON THE MOVE

How do storms move around the world?



NGSS Sensemaking

Students observe patterns of storm movement across North America and around the world to identify the phenomenon anchoring Learning Sequence 3: there are predictable patterns of precipitation movement around the world, and patterns are different in the tropics and midlatitudes. Students generate questions about what is causing these patterns. Students develop initial explanations, drawing on their understanding about how temperature and pressure cause water vapor movement from Learning Sequences 1 and 2.

PERFORMANCE OUTCOME

- Make observations to describe the large-scale motion of water in the atmosphere.
- Describe patterns of how water moves through the atmosphere around the world.

NGSS DIMENSIONS (GRADES 6-8)

- Ask questions that arise from careful observation of phenomena to seek additional information.
- Develop a model to describe unobservable mechanisms.
- Apply scientific ideas to construct an explanation for real-world phenomena.
- Images can be used to identify patterns in data.
- The complex patterns of the changes and the movement of water in the atmosphere are major determinants of local weather patterns.

Teacher Procedures

Global Precipitation Patterns

1. **Navigate from the previous lesson.** At the end of the previous lesson, students followed one storm moving across the United States. Help the class think about how that is a very long way for moisture to travel.

Pose the questions:

- *Where do you think the storm was a day before? Where was it two days before?*
- *Where do you think the moisture for that storm came from?*

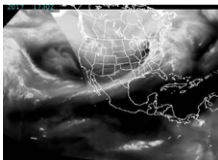
Tell students that in this activity they are going to investigate the global pattern of storm movement.

Note: Prior experience with world maps and the global view of Earth will allow the remaining activities to go more smoothly. Introduce world maps, a globe, and/or Google Earth if needed.

2. **Observe storm movement patterns across North America.** Tell students that one way to identify regular patterns in storm movement is to look at weather patterns from a satellite point of view from above instead of from locations on the ground. Introduce students to the North America Storm Movement video context (see below). Tell students they will make observations from the video:
 - While students watch the video for the first time, have them make observations without taking notes. Point out a cold front over the central U.S. to connect with what students learned in Learning Sequence 2.
 - Watch the video a second time, and now have students take notes and draw the path of the storms on their student activity sheets (*Lesson 12: Step 1*). Focus students on monitoring the direction that storms travel.

LESSON
12

STEP 1



NORTH AMERICA STORM MOVEMENT TIME-LAPSE VIDEO

[Time-lapse video of storm movement across North America from March to April 2017](https://www.youtube.com/watch?v=jC3H2k8IONU&feature=youtu.be)

(<https://www.youtube.com/watch?v=jC3H2k8IONU&feature=youtu.be>)

In this video, the white areas are places with more water vapor (moisture) in the air, which indicates where precipitation is happening. The date appears in the upper left. Students are seeing the curvature of Earth in this video because the satellite is so far away, so due east is in the upper right and due west is in the upper left.

Two cold fronts pass through this video:

- The best option is March 6–8
- A second option is March 29–31

If students would like to see if the same pattern is visible at another time of year, have them watch: [the time-lapse video from January to February](https://www.youtube.com/watch?v=ntC070Sh9t0&feature=youtu.be):

(<https://www.youtube.com/watch?v=ntC070Sh9t0&feature=youtu.be>)



Storyline Link

Continuing a discussion of storm movement is a critical link to maintain coherence as students move from Learning Sequence 2 to Learning Sequence 3.



Patterns in Data

Students identify patterns in storm movement across North America.

3. **Discuss observations as a class.** Draw out ideas around the west to east pattern across North America. Patterns students might notice are as follows:
- Air with water vapor in it generally travels west to east across North America.
 - Air with water vapor in it travels in squiggly, curling, and/or spinning lines.
 - Certain areas have repeated patterns in cloud cover (e.g., the West Coast gets a lot of water vapor from the Pacific Ocean, and some areas, like Mexico, have a “pulsing pattern” in water vapor).
4. **Have students think about why it’s important to understand why storms move in predictable patterns.** In *Lesson 12: Step 2*, have students record ideas about why understanding storm movement patterns might be helpful to people and their communities.

LESSON
12

STEP 2

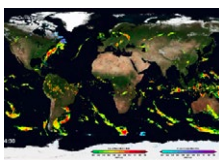
Have students share some of these ideas:

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>How could understanding patterns of storm movement be helpful to people and communities?</i>	<p>For people, it’s helpful to prepare for rain (e.g., like knowing what to wear).</p> <p>For communities, it’s helpful to know when an event is going to happen (e.g., so that people can prepare and stay safe).</p>

5. **Consider how air moves around the world.** Ask students if they think there are similar patterns in other parts of the world and prepare them to look for that in the next video.
6. **Observe precipitation movement patterns around the world.** Introduce students to the NASA rainfall and snowfall video context (see below). Tell students they will make observations from the video. Play the video and mute the sound.
- The first time students watch the video, have them make visual observations without taking notes. Discuss their initial observations of storm movement patterns across North America.
 - Watch the video a second time, now taking notes and drawing on the map in *Lesson 12: Step 3*. You may want to show the video multiple times or pause the video to allow for note taking.

LESSON
12

STEP 3



NASA GLOBAL RAINFALL AND SNOWFALL VIDEO

[Satellite measurements of global precipitation from April to September 2014.](https://pmm.nasa.gov/education/videos/gpms-first-global-rainfall-and-snowfall-map)

(<https://pmm.nasa.gov/education/videos/gpms-first-global-rainfall-and-snowfall-map>)

This two-minute video shows how precipitation moves globally from April to September 2014, with data collected just below the clouds. The green-yellow-red colors indicate rainfall and the blue-purple colors indicate snowfall, which students may not notice in the video. The voiceover explains how the data was collected and some patterns students might notice, so we suggest muting. The video provides a global view and zooms in on the United States (0:25), South America (0:50), and the Atlantic Ocean (1:25).



Patterns in Data

Students identify patterns in storm movement globally.



Storyline Link

The patterns in the NASA global rainfall and snowfall video are the phenomena anchoring Learning Sequence 3. Students will return to these patterns several times.

LESSON
12
STEP 4

- 7. Share observations and generate questions in small groups.** Have students discuss their observations and generate questions about those observations in small groups or pairs.

Question prompts for discussion are in Lesson 12: Step 4.

- *What patterns do you notice about how precipitation moves around the world?*
- *What questions do you have about those patterns?*

- 8. Conduct a whole class discussion.** Discuss the guiding question: “How does precipitation move around the world in predictable patterns?” Draw out students’ ideas working toward the following key patterns:

KEY PATTERN: Precipitation near the equator moves from east to west.

KEY PATTERN: Precipitation in the midlatitudes moves from west to east.

- 9. Generate questions to investigate in Learning Sequence 3.** Have students share their questions about the observed patterns. Add these questions to the Driving Question Board to reference throughout the learning sequence. Focus students on causal questions and elicit responses to the following key questions:

- *Why do storms move in predictable patterns around the world?*
- *Why do storms in the tropics move in different directions than the midlatitudes?*
- *Why do storms move from east to west near the equator in the Northern Hemisphere?*
- *Why do storms move from west to east in the midlatitudes in the Northern Hemisphere?*

Develop Initial Explanations

- 1. Navigate from the previous lesson.** Tell students that they’ll try to answer the following questions in Learning Sequence 3:

- *Why do storms move in predictable patterns around the world?*
- *Why do storms move in different directions in the tropics and midlatitudes?*

LESSON
12
STEP 5

- 2. Form initial ideas about causes of precipitation movement patterns, based on what we already know.** Have students answer the questions in *Lesson 12: Step 5* of their student activity sheets to begin to explain what could be causing the patterns of storm movement. Pull out the Model Idea Tracker and encourage them to use what they learned from Learning Sequences 1 and 2. As students work, circulate and prompt students who are stuck:

- *What do you already know about what causes rain?*
- *What do you already know about what causes air to move?*
- *What would cause storms to move?*
- *How could the same processes affect the whole world?*

Model Ideas that might help students:

- Hot air rises as part of convection (Learning Sequence 1).
- Cool air sinks as part of convection (Learning Sequence 1).
- Air moves from areas of high to low pressure (Learning Sequence 2).



Asking Questions

Students generate questions based on observed patterns of worldwide precipitation movement.



Storyline Link

These questions set the stage for what students will investigate in Learning Sequence 3.



Storyline Link

These questions guide student investigations in Learning Sequence 3.



Cause-Effect

Students start thinking about what could be causing precipitation movement patterns.

3. **Facilitate a whole class discussion about students' initial explanations.** Have students share their initial explanations (answers to *Lesson 12: Step 5: Question 3*). Consider recording multiple and conflicting student ideas in a public place to be revised later (e.g., chart paper, PowerPoint, smart board). If students have conflicting ideas, pull out the important Model Ideas they are drawing on.
4. **Look forward to the next lesson.** Allow multiple explanations to linger. Tell students that there are a few things to investigate. In the next lesson, they'll start by investigating temperature:
 - *How might temperature cause air to move on a global scale?*

**Developing Explanations**

Students develop initial explanations for the observed patterns.


 LESSON
13

HEATING UP

Why is it hotter at the equator than other places on Earth?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(90 minutes)	
<p>Latitudinal Patterns of Temperature Have students revisit the patterns of moving air (Lesson 12) and think about how heat may be involved. Students explore patterns in average annual temperatures worldwide and notice that heat is concentrated at the equator. This leads to the question: Why is it hotter at the equator than other locations around the world?</p>	<p>Lesson 13: Student Activity Sheet </p> <p>Global map of average annual temperatures (http://scied.ucar.edu/sites/default/files/media/images/annual_mean_temperature_graphic_ls3.jpg)</p>
<p>Energy Angles Students investigate different angles of light to think about how the surface of Earth is curved, causing incoming solar radiation to hit more directly at the equator and spread out toward the poles.</p>	<p>Inflatable globe Clipboard Flashlight Ruler Graph paper Colored pencils</p>
<p>Temperature Data Investigation Using GLOBE temperature data for five locations at different latitudes, students use what they have learned about uneven heating at different latitudes to explain the patterns in the five locations.</p>	<p>GLOBE Temperature and Latitude Data card sets (see pages 128-132 of this Learning Sequence)</p>
<p>Model Idea Tracker Students revisit their Model Ideas about uneven heating patterns on Earth and revisit the lesson question: “Why does air move in different ways around Earth?” They think about how uneven heating might help them answer part of this question.</p>	<p>Whiteboard, smart board, or chart paper and markers (to make the Model Idea Tracker)</p>



HEATING UP

Why is it hotter at the equator than other places on Earth?



NGSS Sensemaking

Students identify patterns in average annual temperatures worldwide and figure out the equatorial region is much warmer consistently throughout the year and the midlatitudes have, on average, generally cooler temperatures (although there is seasonal variation). Students then conduct an investigation using a model to explore the causal mechanisms for these temperature differences by latitude and figure out that they are caused by uneven heating of a spherical earth. Students apply this new understanding to explain patterns in temperature in five cities around the world. They will also use this knowledge to help explain global convection in Lesson 14.

PERFORMANCE OUTCOME

- Analyze a model to describe latitudinal variations in the concentration of sunlight and to explain variations in temperature.
- Analyze data to describe global patterns in average annual temperatures.

NGSS DIMENSIONS (GRADES 6-8)

- Use a model to generate data to test ideas about phenomena in natural systems, including those at unobservable scales.
- Analyze and interpret graphical displays of data to identify relationships.
- Construct an explanation using models or representations.
- Construct a scientific explanation based on valid and reliable evidence obtained from students' own experiments.
- Graphs, charts, and images can be used to identify patterns in data.
- Weather and climate are influenced by interactions involving sunlight. These interactions vary with latitude.

Teacher Procedures

Latitudinal Patterns of Temperature

1. **Navigate from the previous lesson.** At the end of the previous lesson, students discussed what they noticed about the movement of weather in North America and globally. Remind students that they have been thinking about how heating can cause air to move and that heating can also cause pressure differences.

The question they are trying to answer now is:

- *How might temperature cause air to move in different ways on a global scale?*

2. **Ask students: “What are some ideas we have about how temperature affects air movement?”** Encourage students to use models and rules of thumb from Learning Sequences 1 and 2 as well as prior knowledge that might help them explain why air would move. Track student thinking on the board. Students will likely say something about hot or cold air (based on what they learned in Learning Sequence 1). Use this idea to link to the next step.

LESSON
13

STEP 1

3. **Show students a global map of average annual temperatures** (*Lesson 13: Step 1*). Ask students to study the map and write down patterns they notice. Then, as a whole class, ask students to share the temperature patterns they noticed. Most students will notice that it is much warmer at the equator than the poles, and there is a gradient between. They may also point out the parallel pattern between the northern and southern hemispheres.

- KEY PATTERN: Temperatures are warmer at the equator and cooler at the poles.
- KEY PATTERN: Temperature follows a pattern of warmer bands in the middle (and around the equator) and cooler bands toward the poles.

4. **Ask students: “Why is it hotter at the equator than other places on Earth?”** Give students time to think about this and write down some initial ideas below the map in *Lesson 13: Step 1* of their activity sheets. Ask students to share their thinking with the class. (Note: Students might say, “The equator is hotter because it’s closer to the Sun.” This is a common student misconception, which should be cleared up by the Energy Angles activity below. If students have this misconception, make sure to address it directly after the Energy Angles activity.) Tell students that in the next activity, they will use a model to explore why it’s hottest at the equator.

Energy Angles

1. **Set up the Energy Angles activity.** Tell students: “We are going to use a flashlight, clipboard, and graph paper to study what happens when sunlight strikes Earth’s surface.” Prior to starting, ask students to explain what the following parts of the set-up represent:

- *What does the flashlight represent? [Sunlight]*
- *What does the clipboard represent? [The Earth’s surface]*



Storyline Link

Revisit the question posed at the end of Lesson 12 to remind students of the focus of this lesson.



Patterns in Data

Students identify patterns in annual average global temperatures.



Going Deeper

Try this additional activity to help students understand the relative size of Earth and the Sun and the distance between them

[Solar Pizza: Size and Scale Model of the Sun-Earth System:](https://sdo.gsfc.nasa.gov/assets/docs/solar_pizza_earth_system/)

https://sdo.gsfc.nasa.gov/assets/docs/solar_pizza_museum.pdf



Developing & Using Models

Students use a model to think about how the Sun’s incoming energy affects temperatures on Earth.

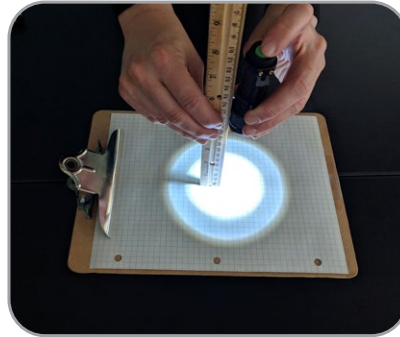
LESSON
13

STEP 2

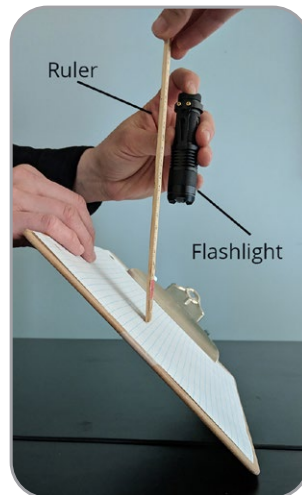
2. Give students about 10 minutes to complete the activity. Use *Lesson 13: Step 2* in the student activity sheet.

NOTES:

- This activity works best in groups of three: one student to hold the clipboard (the surface of the Earth), one student to hold the flashlight and ruler (the Sun), and one student to trace where the light falls on the graph paper (the recorder).
- If possible, darken your classroom or move to a room without windows.
- Students will shine their flashlights down on the paper from straight above while the clipboard is lying flat on the table and again when the clipboard is tilted at an angle (with one edge resting on the table). When creating the angled set-up, tilt the clipboard to about 45 degrees or more.
- Both times the recorder will outline the area that the flashlight lights up. Consider having students use different colors and overlap the images (e.g., shine the light in approximately the same spot both times) to accentuate the differences.
- The distance between the flashlight and the paper will vary depending on how bright your flashlight is. Students will want to choose a distance that allows the entire image to fit on the paper with ample space around the borders. The investigation works best when the flashlight is fairly close to the paper, at a distance of less than 5 cm.
- It is important that the distance between the flashlight and the clipboard stay the same the whole time, but also equally important that the flashlight remain pointing straight down towards the table, even when the clipboard is tilted at an angle. If it helps, point out to students that the Sun is not changing position, but rather we are changing where we are on the Earth; when the Earth's surface is flat we are at the equator, and when the Earth's surface is tilted we have moved far from the equator. Use a globe to point out hypothetical locations on the Earth where we might be "standing."



STRAIGHT ON



TILTED

****To do this activity as a demonstration instead, shine a flashlight straight above onto the ceiling of a darkened room and then angled at the ceiling.****

**Data Analysis & Interpretation**

Students analyze and interpret data from their graph paper to think about where solar radiation is more concentrated and more spread out on Earth.

**Going Deeper**

To collect more data, you can tilt a small photovoltaic cell that is connected to a small motor or voltmeter. Have students measure the amount of tilt and record the amount of energy.

3. **Make sense of the data.** As a whole class, ask students to share their findings from the investigation. Ask students: “When did the light cover more of the paper, straight on or tilted?” Consider asking if any of the groups counted the number of squares illuminated, and if so, which way lighted more squares. Students will notice that there were more squares lit when the clipboard was tilted.

Use the following questions to guide a discussion to make sense of what this means:

- *Was there any difference in the amount of light coming from the flashlight? Did it change or stay the same?* [The amount did not change.]
- *So what happened when you tilted the clipboard?* [The area got bigger; the light spread out.]
- *If you were standing in one of the squares on the clipboard, within which one do you think you would feel the most heat? Why?* [Help students realize that it would be hotter in the circle where the heat is more concentrated and cooler in the circle where the heat is more spread out.]

Now, let’s think about what this means for Earth. Demonstrate shining the flashlight directly at the equator of the inflatable globe, holding the flashlight horizontally. Then, keeping the flashlight horizontal, shine the light toward the poles. If students need support relating their clipboard model to the Earth, have a student hold their clipboard at the equator (so that it is vertical) and then at a high latitude location (so that it’s at an angle). Have them make connections between where the light is more concentrated (the smaller circle on the graph paper) and where the light is more spread out. (Alternatively, project the “What does this mean for Earth’s surface?” slide with the image of the Earth instead of using the physical model.)

LESSON
13
STEP 3

4. **Have students apply these ideas to diagrams of what this means for uneven heating on Earth.** Say: “We are going to use what we just did with the flashlights and clipboards to think about what this would look like on Earth’s surface.” Direct them to *Lesson 13: Step 3*. Ask, “What do you notice about this image?” Students should notice that the “clipboard” from *Lesson 13: Step 2* is now placed at certain points on Earth (e.g., the slanted clipboard could be the Earth’s surface at midlatitudes and the non-slanted clipboard could be the Earth’s surface at the equator). Students should think about where solar radiation is more concentrated and where it is more spread out (less concentrated) as they answer the questions.
5. **What did this activity help us figure out related to our question: Why is it hotter at the equator than other places on Earth?** Ask students to summarize what they learned from the Energy Angles activity.

Write these ideas on the Model Idea Tracker.

- Sunlight (solar radiation) is more concentrated at the equator because incoming sunlight shines directly on the equator, concentrating it in a smaller area.
- Sunlight (solar radiation) is more spread out toward the poles because incoming sunlight hits the surface at an angle, spreading the light out over a larger area.
- The amount of concentrated solar radiation that warms the land influences air temperatures just above the land. More concentrated solar radiation causes higher air temperatures. More spread out solar radiation causes cooler air temperatures.

Note: This is where you can end the lesson for the first day.



Storyline Link

Revisit where students are in Lesson 13 if this lesson is taught across multiple class periods.

TEMPERATURE DATA INVESTIGATION



- Tell students they are going to look closer at temperature data by latitude.** If you split this lesson across two days of class time, begin day two by asking students to describe general differences in temperature between Earth's poles and the equator and why they believe there are different temperatures. Revisit the Model Idea Tracker as needed to remind students where they are in the investigation of uneven heating between the equator and the poles.
- Divide students into groups and preview the GLOBE Temperature and Latitude data graph cards, location cards, and maximum/minimum temperature cards to orient students to the activity.** Pass out a card set to each group. Ask students what they notice about the graphs. Students may notice the following:
 - The x-axis is time and this data was collected over several years.
 - The data in different places was not collected over the same time period.
 - Some graphs have strong shifts in temperature over seasons, and some locations have little variation.

Tell students that GLOBE students in five locations around the world took measurements of maximum daily temperature (the warmest temperature each day) and that these are the graphs of that data. Their task is to figure out the location of the data based on what they understand about how temperatures vary by latitude. (Note: The graphs introduce seasonal shifts in temperature, which is NOT part of this unit. If you have already taught seasons in your class, this is a good place to have students make connections. If you have not taught seasons in your class, ask students to focus on the range of temperatures, focusing on where warmer and cooler temperatures are and not the seasonal shifts within the year.)

GLOBE Locations:

- Juuan Lukio/Poikolan Koulu, Finland*
- WANAKA Field Station, Vermont, USA*
- Many Farms High School, Arizona, USA*
- Hamzah Bin Abdulmutalib Secondary School at Jeddah, Saudi Arabia*
- Wp/Minu/D S Senanayake College, Sri Lanka*

- Allow students time to match the graphs/temps/locations for each of the five locations.** Have the groups share their initial matches with another group and discuss any differences before they begin to record them on the student activity sheet.

- In Lesson 13: Step 4, have students complete their explanations of locations based on the temperature and latitude data.** Using the clues below, students can revisit their matches and then write down their final best guesses.

Clue 1: Seasonal differences (fluctuations from cold to warmer temperatures) are stronger at higher latitude (further from the equator). At or near the equator, there is usually no seasonal difference in temperature.

Clue 2: Temperatures are warmer at low latitude (close to the equator) than at high latitude (far from the equator).

CORRECT MATCHES

Location	Graph	High/Low
Finland	B	I
Vermont	E	J
Arizona	A	H
Saudi Arabia	C	F
Sri Lanka	D	G



Data Analysis & Interpretation

Students analyze and interpret temperature data and latitude for five GLOBE locations.

LESSON
13

STEP 4

MODEL IDEA TRACKER**1. Revisit the Model Idea Tracker to summarize Model Ideas about uneven heating.**

Summarize the Model Ideas from this lesson.

- Sunlight (solar radiation) is more concentrated at the equator because incoming sunlight shines directly on the equator, concentrating it in a smaller area.
- Sunlight (solar radiation) is more spread out toward the poles because incoming sunlight hits the surface at an angle, spreading the light out over a larger area.
- The amount of concentrated solar radiation influences air temperatures; more concentrated solar radiation causes higher air temperatures and more spread out solar radiation causes cooler air temperatures.

Then ask students: "So we know that Earth is heated unevenly by the Sun. Some places have more direct solar radiation; other places have more spread out solar radiation. That causes temperature differences on Earth. But how does that have anything to do with how air moves?"

Give students a few minutes to ponder this question. Ask if they can pull from the Model Idea Tracker, particularly as it relates to pressure differences and air temperatures. Some students may say something about different air temperatures being related to convection. Push them to explain how temperature difference might cause convection. Build on this idea by telling students that they will think about temperature differences and how they cause air to move in the next lesson.

Tell students: "We saw different patterns of storm movement in the tropics and the midlatitudes. Next time, we'll start by thinking solely about the tropics and how uneven heating and air movement relate in that region."

- *How does uneven heating relate to air movement in the tropics?*

LESSON
14

AIR MOVEMENT IN THE TROPICS

How and why does air move in the tropics?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(90 minutes)	
<p>Develop a Working Model Students pull their ideas together from Learning Sequences 1, 2, and 3 to develop an initial model to explain how and why air moves in the atmosphere in the tropics.</p>	<p>Lesson 14: Student Activity Sheet </p> <p>Optional: NASA rainfall and snowfall video</p>
<p>Convection Demonstration Students observe convection in a class demonstration. Students figure out that winds move toward the equator in global convection. Students then add these ideas to the Model Idea Tracker.</p>	<p>Clear tub Cold water Red and blue food coloring Two pipettes Kettle and near boiling water Five insulated cups Optional: Device for time-lapse/ slow-motion video</p>
<p>Global Air Circulation Diagram Students review a diagram of global air circulation and record observations, initial explanations, and questions. In a whole class discussion, students discuss how convection happens on a global scale and add additional Model Ideas to the Model Idea Tracker.</p>	<p>Whiteboard, smart board, or chart paper and markers (to make the Model Idea Tracker)</p>
<p>Consensus Model: Air Movement in the Tropics Students use the Model Idea Tracker to develop a Consensus Model for explaining how and why air moves in the tropics. Students develop models in small groups and then share their models with the class and come to consensus.</p>	<p>Whiteboard, smart board, or chart paper and markers (to make the Consensus Model)</p>

LESSON
14

AIR MOVEMENT IN THE TROPICS

How and why does air move in the tropics?



NGSS Sensemaking

Students develop a model to explain how and why air moves in large-scale convection in the tropics. Students develop an initial model drawing on understandings from Learning Sequences 1, 2, and 3. Students gather evidence about how air moves in global convection from critical review of a diagram and a convection demonstration. Students revise models in small groups and develop a class Consensus Model.

PERFORMANCE OUTCOME

- Develop a model to show how air is circulating through the atmosphere in the tropics and midlatitudes.

NGSS DIMENSIONS (GRADES 6-8)

- Develop a model to describe unobservable mechanisms.
- Construct an explanation using models or representations.
- Weather and climate are influenced by interactions involving sunlight and the atmosphere. These interactions vary with latitude, which can affect atmospheric flow patterns.

Teacher Procedures

Develop a Working Model

- 1. Revisit the Learning Sequence 3 phenomenon and question: Why do storms move in predictable patterns around the world?** Remind students that the class is investigating how air moves on a global scale because air movement is related to patterns in storm movement. (Optional: Show the NASA global rainfall and snowfall video from Lesson 12 to remind students of the precipitation movement pattern in the tropics.)
- 2. Navigate from the previous lesson.** At the end of the previous lesson, students figured out that solar radiation causes uneven heating of Earth, which leads to air temperature differences. Students figured out that air at the equator will be warmer than air in the midlatitudes. Remind students of the next question to investigate:
 - *How does uneven heating relate to air movement in the tropics?*
- 3. Prepare students to develop a Working Model.** Tell students they will develop a Working Model to explain how and why air moves in the tropics. Have students review the Model Idea Tracker to draw on ideas from lessons 1 to 13. Tell students that not all ideas will be helpful, but some might.
 - Encourage students to draw on ideas from the previous lesson about solar radiation as well as ideas from Learning Sequence 1 about how temperature relates to air movement and ideas from Learning Sequence 2 about how pressure relates to air movement.
 - Remind students that the purpose is for them to try to draw on their existing knowledge to start developing an explanation. They don't need to be certain about their models at this point.
- 4. Orient students to the illustration of the Earth's atmosphere in Lesson 14: Step 1 of the student activity sheet.** Show the cross section of Earth's atmosphere (slide: Layers of the Atmosphere) and relate it to the illustration on their activity sheets. While the atmosphere does have four distinct layers, the illustration on their activity sheets is focusing just on the Earth's surface and the troposphere layer of the atmosphere, because this is where all weather occurs.
- 5. Students record an initial Working Model.** In *Lesson 14: Step 1* of their student activity sheets, students record a model that explains how air movement in the tropics relates to latitude. Encourage students to share their working models with others as they finish.

Use the following prompts to guide students as you circulate the class:

- *Where might air be rising from Earth's surface to the atmosphere and why?*
- *Where might air be sinking from the atmosphere to Earth's surface and why?*



Storyline Link

Students remember that they're exploring air movement because precipitation is moisture in the air, and they are trying to explain patterns in global storm movement.



Developing & Using Models

Students draw on Model Ideas from Learning Sequences 1, 2, and 3 to develop a Working Model to explain how air moves in the tropics.

LESSON
14
STEP 1

Convection Demonstration



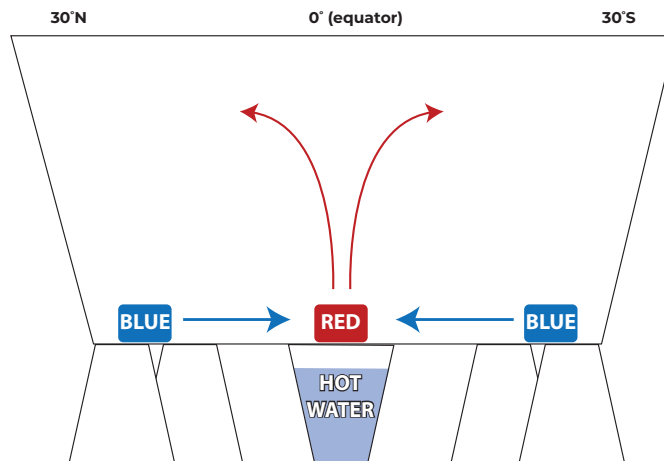
1. **Introduce the goal of the Convection Demonstration.** Tell students that the goal of this demonstration is to help them think about how and why air moves across the Earth's surface in global convection near the equator. Students can also make observations about the rest of the convection cycle.



Storyline Link

In this activity, students think about how air would move across Earth's surface in global convection, which would cause patterns in storm movement.

CONVECTION DEMONSTRATION



MATERIALS:

- Clear tub (about the size of a shoebox)
- Cold water (enough to fill the clear tub $\frac{3}{4}$ full)
- Red and blue food coloring
- Two pipettes
- Hot water
- Device to heat water (e.g., kettle)
- Five cups of the same height (four to hold up the tub and one for hot water)

PREPARATION:

- Fill the clear tub with cold water and place the tub on top of four cups. Let the water settle. Place the tub in front of a light-colored background.

TO BE DONE WITH STUDENTS IN CLASS:

1. Heat water using a kettle and fill an insulated cup.
2. Use a pipette to carefully place a large drop of red food coloring at the bottom of the center of the tub.
3. Use a pipette to carefully place two large drops of blue food coloring at the bottom of each side of the tub.
4. Place the cup with hot water underneath the red drop of food coloring at the center of the tub.

[Video showing this demonstration](https://scied.ucar.edu/video/convection-demonstration)

(<https://scied.ucar.edu/video/convection-demonstration>)

LESSON
14

STEP 2

2. **Discuss what each part of the tank represents.** Orient students to the demonstration set-up and discuss what each part represents. Students can fill in the middle column (“Part of the real world”) in *Lesson 14: Step 2* as you discuss.
- The water in the tank represents air. This model uses water to simulate air because both air and water are fluids, so they behave similarly, but water can be seen.
 - The red food coloring represents air at the equator.
 - The blue food coloring represents air at 30°N and 30°S.
 - The cup full of hot water represents solar radiation.
 - The bottom of the tank represents Earth’s surface.

Have students work with a partner to fill out the third column (“Why are they alike?”) of the analogy map in *Lesson 14: Step 2*. Students should come up with reasoning to explain why the analogy works (e.g., Why is red coloring a good choice to represent air at the equator?).

3. **Prepare for observations.** Students may wish to make a video or take photos. They might sketch or write about the changes. Explain that having several ways to document what is happening is a good idea because different types of data can be used together to help us understand what is happening. Have students plan how they will document what happens in the tank.
4. **Set-up the demonstration.** Explain how the demonstration will be completed. The key idea here is that students watch what is happening along the bottom of the tank, as it represents air movement, or winds, across Earth’s surface. Ask students to predict what will happen when the cup of hot water is added. Put the red and blue food coloring drops at the base of the tank. Heat the water, add it to the cup, and place the cup with hot water under the red food coloring in the tank. It will take about one minute for the red dye to start rising and convection to start. The blue dots should also slowly begin to pull towards the center of the tank (towards the red dot).

LESSON
14

STEP 3

5. **Make observations.** Have students draw what they notice happening in the tank in *Lesson 14: Step 3* of their activity sheets. Students should observe that the red food coloring rises and the blue food coloring is pulled in from the sides of the tank to the middle of the tank. Have students record their ideas about what they see, why they think it is happening, and what they wonder about in the boxes below their drawings.

LESSON
14

STEP 4

6. **Relate the convection demonstration to how and why air moves in the tropics.** Orient students to the model, pointing out that we are focusing only on the convection cells near the equator. Have students develop a model in *Lesson 14: Step 4*, using their observations of the tank to describe how air is moving in the tropics (between 30°N and 30°S of the equator). Students should be able to explain why air is rising and sinking.
7. **Share observations and lead a discussion of the demonstration.** Have students explain what they observed and why it happened. Use the following questions to guide this discussion:

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>What happened to air at the surface of the Earth when it received direct heat?</i>	The air near the equator heated up from the Sun and rose.
<i>What happened to the pressure where the warm air rose?</i>	The warm rising air caused an area of low pressure.
<i>Why would the air move from the cool location to the warm location?</i>	As the warm air rises, it creates an area of low pressure. Cool air moved toward the area of low pressure across the Earth. That's the wind we would feel.

Students may need support to understand why the cool air is pulled across Earth's surface toward the equator. This is a good time to remind students what they know about pressure and how air moves from high to low pressure. Students may also not realize that this horizontal movement represents winds. Have them think about what they would feel if they stood at the bottom of the tank. Remind them that the bottom of the tank represents the Earth's surface.

8. Revisit the Model Idea Tracker to summarize Model Ideas about air movement.

Summarize the new Model Ideas from this lesson and record them on the Model Idea Tracker.

Model Ideas:

- As warm air rises at the equator, it creates an area of low pressure.
- Cooler air with higher pressure moves across Earth's surface toward the area of low pressure to replace the rising warm air.
- Horizontal movement of air across Earth's surface is wind.

Global Air Circulation Diagram



Note: Do not hand out *Lesson 14: Step 5* until students get to this point, as the previous steps involve students discovering the pattern of convection cells that is provided here.

LESSON 14 STEP 5

- 1. Introduce the Global Air Circulation Diagram in Lesson 14: Step 5.** Orient students to this diagram and point out that it shows how air moves around the whole world, not just in the tropics.
- 2. Have students create a model of air pressure and humidity.** Annotating the illustration in *Lesson 14: Step 5*, students should create a model locating the areas of low and high atmospheric pressure and the locations that are likely to be cloudy because air is rising. Use the arrows indicating air movement as clues.
- 3. Lead a class discussion about the diagram.** Focus students on convection near the equator and encourage students to draw on their understanding of convection from Learning Sequence 1 and high and low pressure from Learning Sequence 2 to explain air movement in tropical convection. The one important thing for students to notice in the midlatitudes at this point is that convection moves in the opposite direction. This will be revisited in Lesson 15. Use the prompts below to guide your discussion.



Disciplinary Core Idea
Students deepen their conceptual understanding about how temperature and pressure causes air movement in convection. Students expand their understanding that convection also happens on a global scale.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>Where is air rising from Earth's surface into the atmosphere and why?</i>	Warm air is rising at the equator because there is more concentrated sunlight (solar radiation) there. Warm air is also rising at the top of the midlatitudes.
<i>Worldwide, where is air sinking from the atmosphere to Earth's surface and why?</i>	Cool air is sinking at 30°N and 30°S. Cool air is also sinking at the poles.
<i>How is air moving across Earth's surface and why?</i>	We're not sure, but the arrows are pointing toward the equator, so it looks like air is moving toward the equator.
<i>Where do you think there are areas of high and low pressure and why?</i>	We think there's low pressure at the equator where the warm air is rising, like the isolated storm. There's probably high pressure around 30°N and 30°S where cool air is sinking.

4. Document new Model Ideas on the Model Idea Tracker at the end of the discussion.

Students figure out the following:

- Warm air is rising at the equator because of concentrated sunlight (solar radiation), which heats air, causing it to rise. An area with rising air has low pressure.
- Cool air is sinking at 30°N and 30°S, which is an area of high pressure.
- Convection happens on a global scale.

5. Ask students what we would experience on the surface of the Earth. Have students wonder about what the air movement would be like if we were standing at the surface of the Earth near the equator. Tell students that air movement across Earth's surface is what we experience as wind. It's okay if students are not sure about this yet.

- *If you stood just north of the equator, where would you feel winds coming from?*
- *If you stood just south of the equator, where would you feel winds coming from?*

Consensus Model: Air Movement in the Tropics

1. Revisit the Learning Sequence 3 phenomenon and question: Why do storms move in predictable patterns around the world? Remind students that the class is investigating air movement patterns because precipitation is moisture in the air. Remind students that we're focusing only on air movement in the tropics for now. Review the question that the Consensus Model will help us answer:

- *How and why does air move in the tropics?*



Assessment

Use this discussion to formatively assess student learning about global convection.



Developing & Using Models

Use the Model Idea Tracker to document new rules students figured out about air circulation in the tropics. Remember these are general rules of thumb that will be helpful for explaining global storm movement patterns.



Storyline Link

Students remember that they're exploring air movement because precipitation is moisture in the air, and they are trying to explain patterns in global storm movement.

2. Take stock of ideas from the Model Idea Tracker that will help answer this question.

Have students nominate ideas from the Model Idea Tracker that they think will be helpful for answering this question. All of the ideas from Learning Sequence 3 will be helpful as well as some ideas from Learning Sequences 1 and 2 about warm air rising, cool air sinking, and air moving from high to low pressure.

- 3. Develop a class Consensus Model.** Have small groups consider ideas from the models they created in *Lesson 14: Step 4 and Step 5* and the ideas from the Model Idea Tracker. Have each group present which ideas they propose including in the Consensus Model. As small groups present, have students discuss if they agree or disagree with the ideas in each groups' model. Come to consensus about what should be in the model and document a Consensus Model in a public space that reflects agreed upon ideas.

KEY MODEL IDEAS THAT SHOULD BE REPRESENTED IN THE CONSENSUS MODEL

- As warm air rises at the equator, it creates an area of low pressure.
- Sunlight (solar radiation) is more concentrated at the equator because incoming sunlight shines directly on the equator, concentrating it in a smaller area.
- Sunlight (solar radiation) is more spread out toward the poles because incoming sunlight hits the surface at an angle, spreading the light out over a larger area.
- The amount of concentrated solar radiation influences air temperatures; more concentrated solar radiation causes warmer air temperatures and more spread out solar radiation causes cooler air temperatures.
- There are more areas where warm air is rising near the equator and more areas where cool air is sinking at 30°N and 30°S.
- Cooler air moves along the surface of the Earth toward the area of low pressure to replace the rising warm air.
- Horizontal movement of air along the surface of the Earth is wind, which causes storms to move.

**Developing & Using Models**

Students use ideas from the Model Idea Tracker to develop a class Consensus Model to explain how and why air moves in the tropics. As students work in groups, they do not need to agree on all parts of the model. They contribute questions to the Consensus Model discussion. Have the Model Idea Tracker and evidence from previous activities ready to revisit during the consensus discussion to help resolve disagreements.

**Assessment**

Students' small group models may serve as tools for formative assessment.

LESSON 15

A CURVEBALL

When air and storms move, why do they curve?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(55 minutes)	
<p>Use the Consensus Model Students use the Consensus Model to predict how air moves across Earth’s surface in the tropics. Students review observed storm movement patterns in the tropics and realize that the model doesn’t explain why precipitation at the equator moves from east to west.</p>	<p>Lesson 15: Student Activity Sheet </p>
<p>Coriolis Effect Reading Students gather evidence from an article that explains the Coriolis effect and how Earth’s rotation causes air to curve. Students discuss the Coriolis effect in a whole class discussion and add new ideas to the Model Idea Tracker.</p>	<p>Round balloons, markers</p>
<p>Explaining Storm Movement Students use their global air circulation models and new ideas about the Coriolis effect to explain where precipitation would travel in the Philippines and where they live.</p>	



A CURVEBALL

When air and storms move, why do they curve?



NGSS Sensemaking

Students use the Consensus Model to explain precipitation movement patterns near the equator and realize their model does not account fully for the phenomenon. Students critically read a scientific text to gather information about how the rotation of Earth causes winds to curve, the Coriolis effect. Students use their Consensus Model and new ideas about the Coriolis effect to explain patterns of storm movement in two new locations.

PERFORMANCE OUTCOME

- Use knowledge of surface wind patterns to make a prediction about the movement of a storm.

NGSS DIMENSIONS (GRADES 6-8)

- Use a model to predict phenomena.
- Evaluate limitations of a model for a proposed tool.
- Critically read scientific texts adapted for classroom use to obtain scientific information to describe evidence about the natural world.
- Weather and climate are influenced by interactions involving sunlight and the atmosphere. These interactions vary with latitude, which can affect atmospheric flow patterns.
- Phenomena may have more than one cause.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Patterns of change can be used to make predictions.

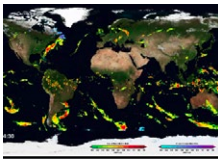
Teacher Procedures

Use the Consensus Model

- Navigate from the previous lesson.** Remind students that they just developed a Consensus Model to explain air movement in the tropics. Remind students of the Learning Sequence 3 question and how it connects to air movement.
 - Why do storms move in predictable patterns around the world?*
- Use the model to predict how storms move in the tropics.** Have students use their Air Movement in the Tropics Consensus Model to predict how air or wind moves across Earth's surface in the tropics. Orient students to where storms would occur in their model (at the bottom of the atmosphere). Students should deduce that, because of convection, storms would move towards the equator in the tropics.
 - Based on what you know about air movement in the tropics, predict storm movement in the tropics.*
- Compare predictions to observed storm movement patterns.** Re-watch the NASA global rainfall and snowfall video from Lesson 12: Step 3 and focus students on storm movement in the tropics. After watching the video, students record the answer to the question below in *Lesson 15: Step 1* of their student activity sheets. Students should notice very obvious patterns of storms moving from east to west that our model doesn't explain.
 - What kind of movement do you see that isn't explained by the model for air movement in the tropics that you made at the end of Lesson 14?*

LESSON
15

STEP 1



NASA Global Rainfall and Snowfall Video

(<https://pmm.nasa.gov/education/videos/gpms-first-global-rainfall-and-snowfall-map>)

The video shows how precipitation moves globally from April to September 2014, with data collected just below the clouds. The green-yellow-red colors indicate rainfall and the blue-purple colors indicate snowfall, which students may not notice in the video. The voiceover explains how the data was collected and some patterns students might notice, so we suggest muting. The video provides a global view and zooms in on the United States (0:25), South America (0:50), and the Atlantic Ocean (1:25).

- Discuss the limitations of the model.** Remind students that all models need to be revised and tested and revised again. This model is not yet helping us fully explain observed patterns of precipitation movement at the equator, nor is it addressing questions about precipitation movement generated in Lesson 12 that are on the Driving Question Board:
 - Why does precipitation move from east to west near the equator?*
 - Why does precipitation move from west to east in the midlatitudes?*
 - Why does precipitation move in different directions in the tropics and midlatitudes?*



Storyline Link

Students review the phenomenon and remember that they're exploring air movement because precipitation is moisture in the air, and they are trying to explain patterns in global storm movement.



Developing & Using Models

Students realize the limitations of their model and that their model does not yet fully help them explain the observed phenomenon.

CORIOLIS EFFECT READING

LESSON 15
STEP 2

- Navigate from the previous activity.** Tell students that the model they developed explains the north-south aspect of storm movement in the tropics but not the east-west movement.
- Read the first paragraph in Lesson 15: Step 2 about the Coriolis effect.** Read this aloud with your students to introduce the new idea that the spinning of the Earth deflects winds.
- Observe the Coriolis effect with a quick activity:** Provide pairs of students with a round balloon and marker. Instruct students to inflate the balloon and draw an equator around the widest point in the center of the balloon. Also draw on the balloon “about” where the 30° N latitude and 30° S latitude lines would be. Tell students that this is a simple model of the Earth. Have one student hold the balloon at chest height (they should be able to look down at the top of the balloon) while the other draws an arrow starting at 30° N going toward the equator. Then have the student holding the balloon slowly rotate it counterclockwise (to model the Earth spinning on its axis) as their partner draws another arrow, starting again from the same point on their balloon. Students should notice that when their model of Earth was turning, the arrow curved, but when their model wasn’t spinning, it did not.
- Finish Reading about the Coriolis effect in Lesson 15: Step 2.** Set the purpose of reading an article as a method to help students gather evidence to explain the east-west storm movement they observed in the video as well as additional evidence to explain the west-east storm movement in the midlatitudes. Students can read individually or as a whole group. Prompt students to *Stop and Think* as they encounter questions in the text. These questions are to help students make connections between the information they read and their previous observations.
- Discuss the Coriolis effect.** Lead a whole class discussion about the Coriolis effect. The big ideas students should walk away with are that the winds do move north and south, caused by convection, and they also move east and west, caused by the Earth’s rotation.

The unit thus far focused on explaining the north-south movement of air in tropical convection. Students may struggle to see how air moves across Earth’s surface toward the poles in midlatitude convection. You can help students see that convection in the midlatitudes travels in the opposite direction.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>Why does the air in the tropics curve east to west?</i>	The Earth rotates so air that was moving toward the equator curves and moves to the west.
<i>How does air move across Earth’s surface in midlatitude convection?</i>	Air moves toward the poles. This is the opposite direction as in the tropics.
<i>Why does the air in the midlatitudes move west to east?</i>	The Earth rotates so air that was moving towards the poles curves and moves to the east.



Storyline Link

Students are motivated to gather more evidence to explain the phenomenon.



Literacy Connection

Students read non-fiction texts and are prompted to make connections and to synthesize ideas.



Going Deeper

Have students blow up a balloon and use a marker to draw an equator. Make the knot the South Pole and the top of the balloon the North Pole. Have one partner rotate the balloon left to right, simulating Earth’s rotation, while the other partner slowly tries to draw a straight line from the North Pole to the equator. Next, the partner with the marker will draw a straight line from the South Pole to the equator. Students see how the movement “curves” in opposite directions in the northern and southern hemispheres.

6. **Add new ideas to the Model Idea Tracker.** Summarize the new model ideas developed out of this discussion and add them to the Model Idea Tracker.

Model Ideas

- In the tropics, air moves across Earth's surface towards the equator due to convection.
- In the tropics, air moves across Earth's surface east to west due to the Earth's rotation.
- In the midlatitudes, air moves across Earth's surface toward the poles due to convection.
- In the midlatitudes, air moves across Earth's surface west to east due to the Earth's rotation.

EXPLAINING STORM MOVEMENT

1. **Navigate from the previous activity.** Tell students that with their new ideas about the Coriolis effect, they are now prepared to explain more of the patterns in storm movement they observed in the tropics and the midlatitudes.

LESSON
15

STEP 3

2. **Record a final explanation.** In *Lesson 15: Step 3*, have students use their model and new ideas about the Coriolis effect to record an explanation that describes where it is likely that storms will originate in the Philippines and where they live.

3. **Lead a whole class discussion.** Have students share their explanations for where weather comes from where they live and why this understanding is important for their daily lives. Have them connect back to their responses from Lesson 12.

- *Where is it likely that storms originate where we live?*
- *Why is being able to anticipate where storms come from important for communities?*
- *How can we use our understanding of weather to prepare for the impacts of storms?*

LOOK
BACK

LESSON
11

STEP 2

4. **Connect back to the Anchor.** Have students look back at their Lesson 11 weather map model. On a world map, globe, or Google Earth, indicate the location of Colorado. Ask students to identify what direction storms are likely to travel based on its latitude. (Students should recognize that it is in the midlatitudes so storms will tend to move from west to east.) Have students add an arrow to their weather map models to indicate the direction that the storm is trying to move. Ask students what stopped the storm from moving (high pressure to the east, north, and south).

END OF SEQUENCE ASSESSMENT

Assess student learning with the Learning Sequence 3 assessment. You can find the assessment item bank and rubric in the Assessments section of *GLOBE Weather*.



Storyline Link

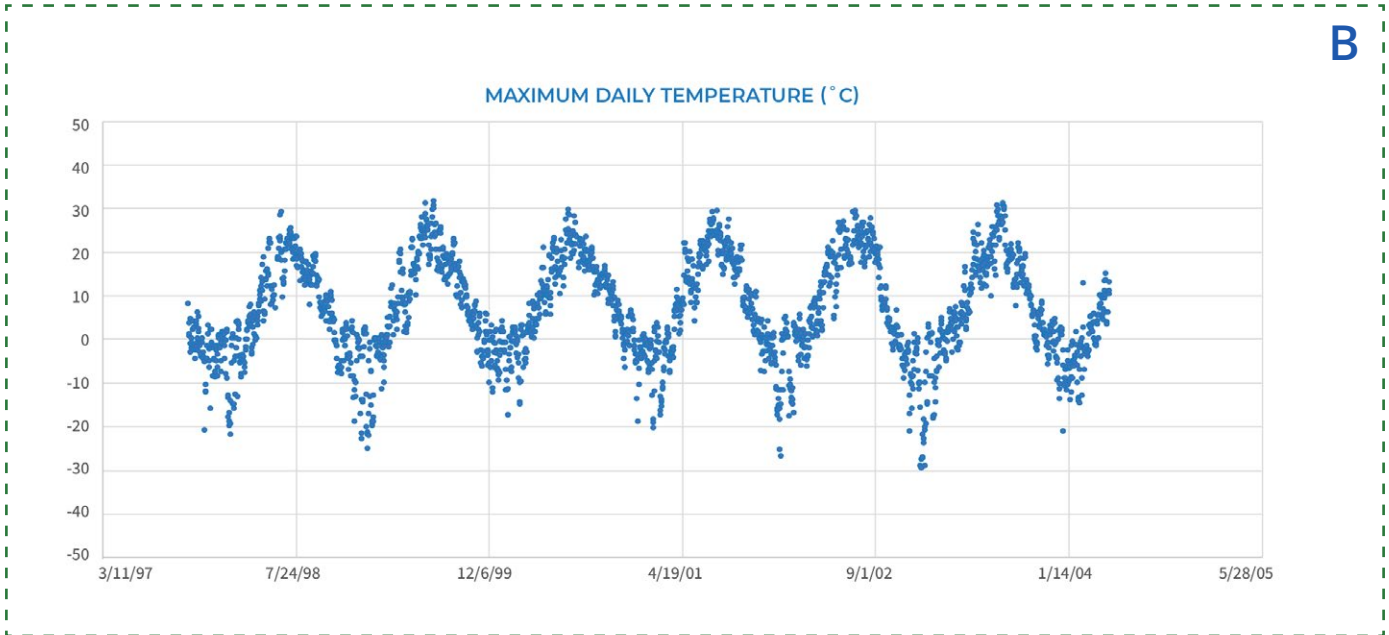
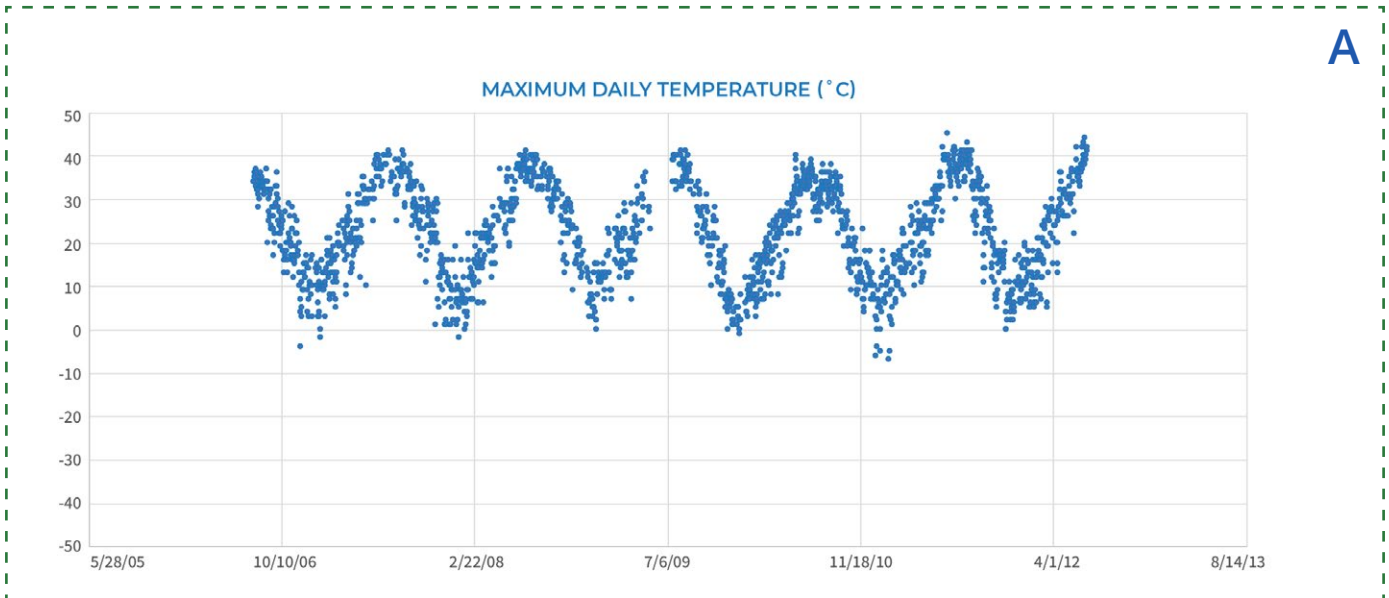
Students are motivated to gather more evidence to explain the phenomenon.



Assessment

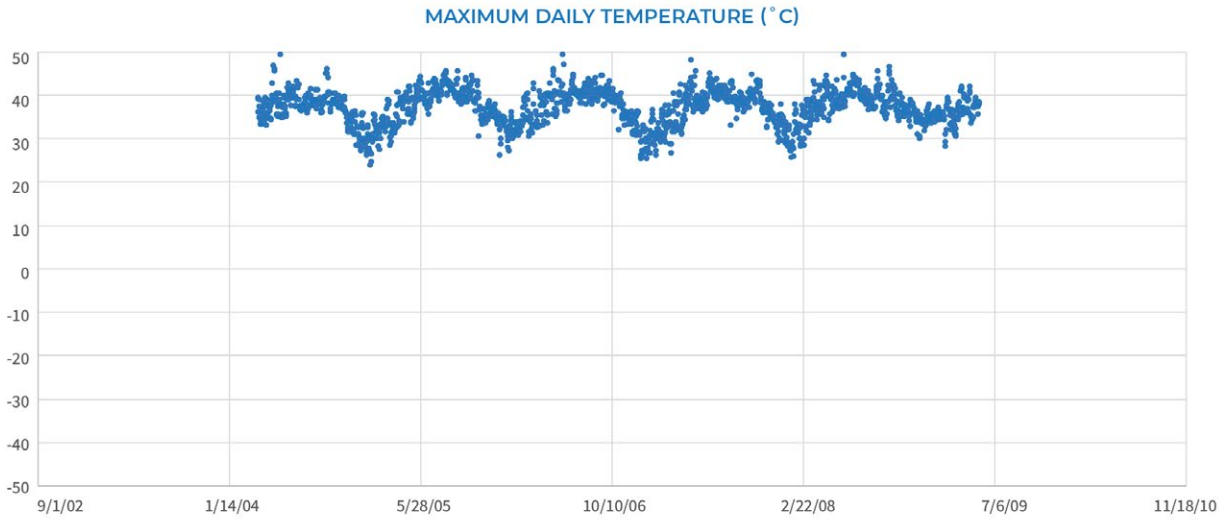
This final individually written explanation can serve as one of the summative assessments for this learning sequence.

NOTE: Cut apart the graphs and maps on the following four pages for each student group. (Use the highest/lowest temperature cards if students need support to interpret graphs.)

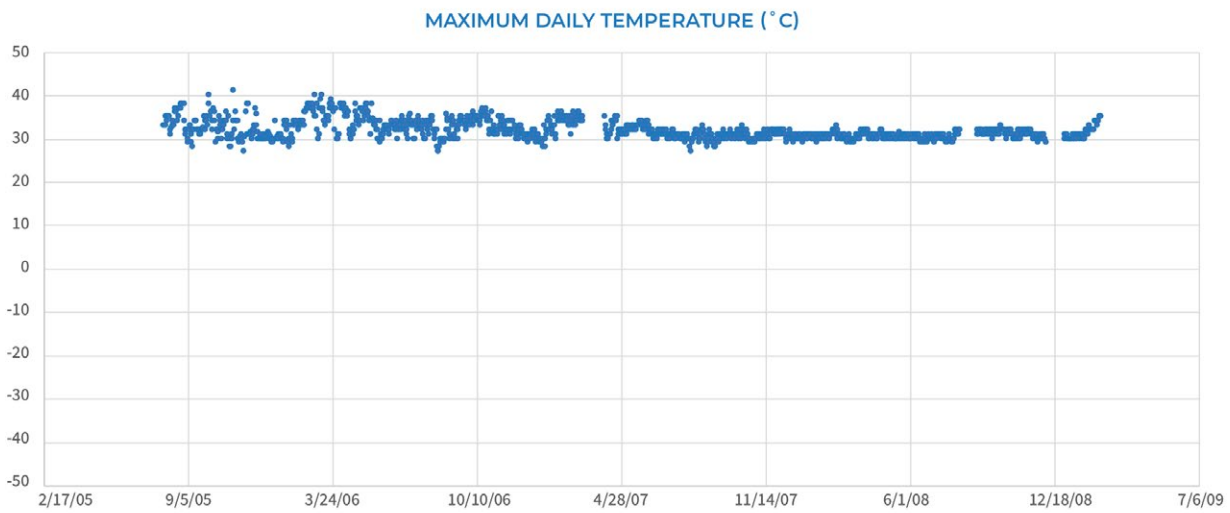


F	lowest max temperature 24 ° C	highest max temperature 49 ° C
G	lowest max temperature 27 ° C	highest max temperature 41 ° C
H	lowest max temperature -7 ° C	highest max temperature 44 ° C
I	lowest max temperature -30 ° C	highest max temperature 30 ° C
J	lowest max temperature -22 ° C	highest max temperature 35 ° C

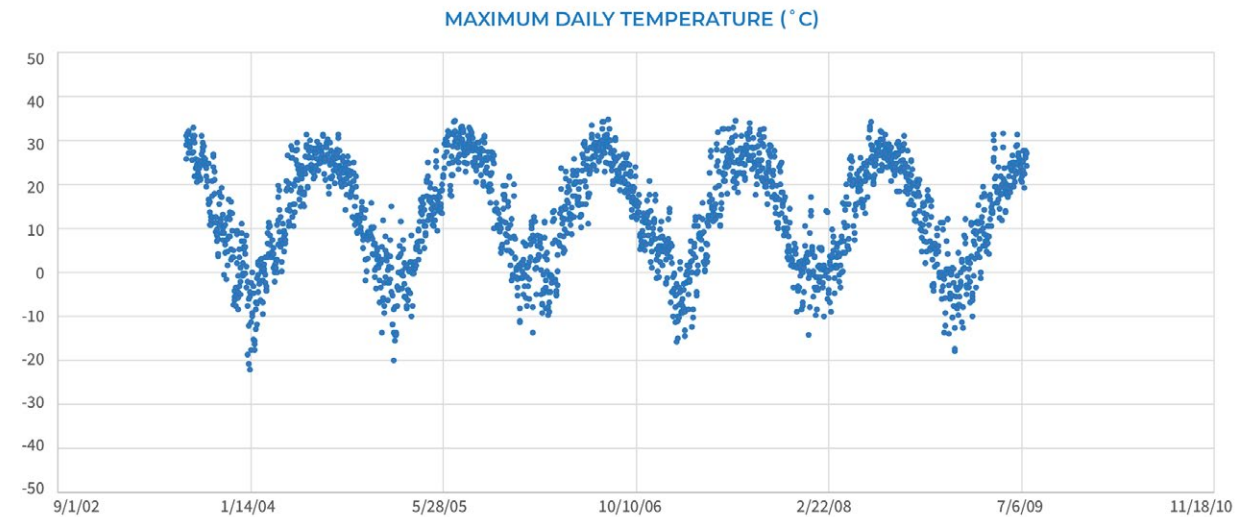
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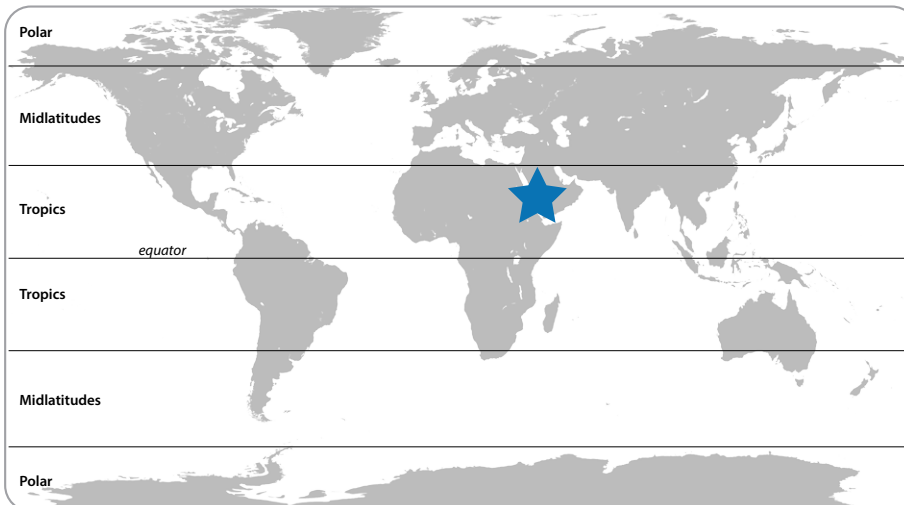


Location:
Saudi Arabia

Latitude:
21.3725

Distance from
the equator:
2,372 km

N

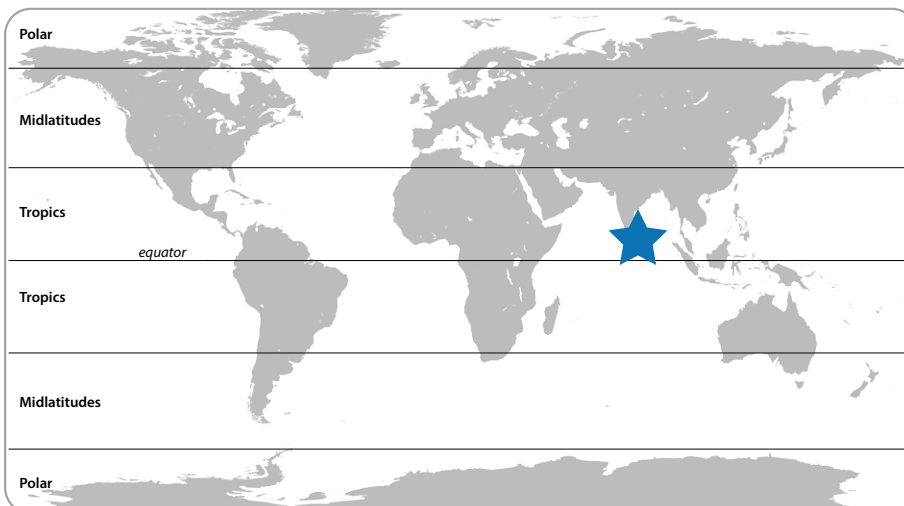


Location:
Sri Lanka

Latitude:
7.1438

Distance from
the equator:
793 km

O

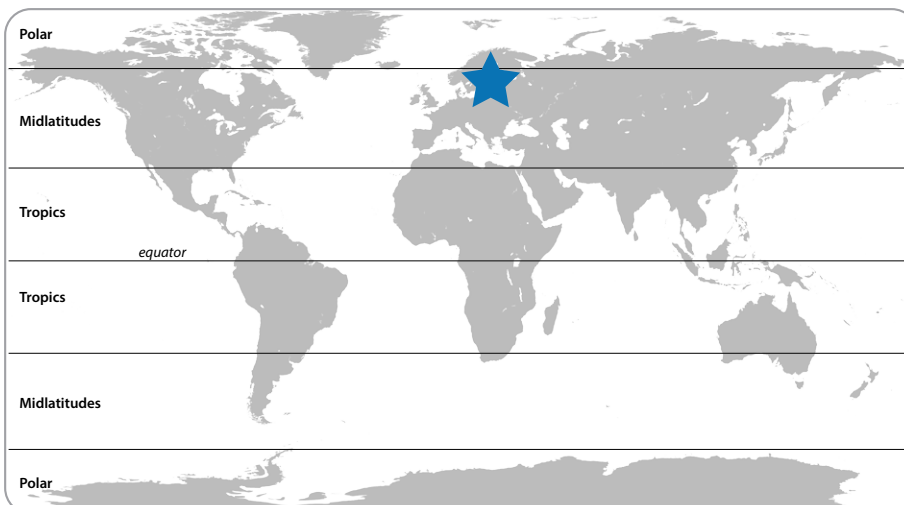


Location:
Finland

Latitude:
63.2377

Distance from
the equator:
7,020 km

K

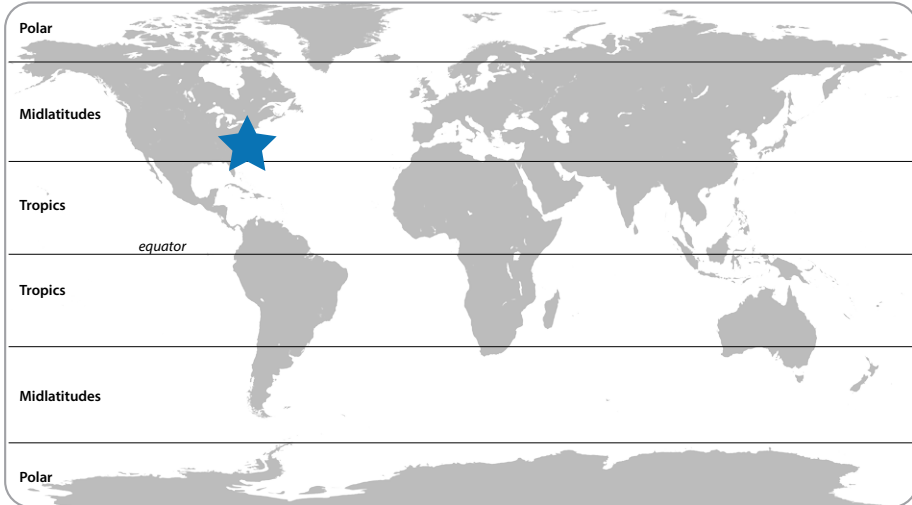


Location:
Vermont, US

Latitude:
44.675

Distance from
the equator:
4,959 km

L

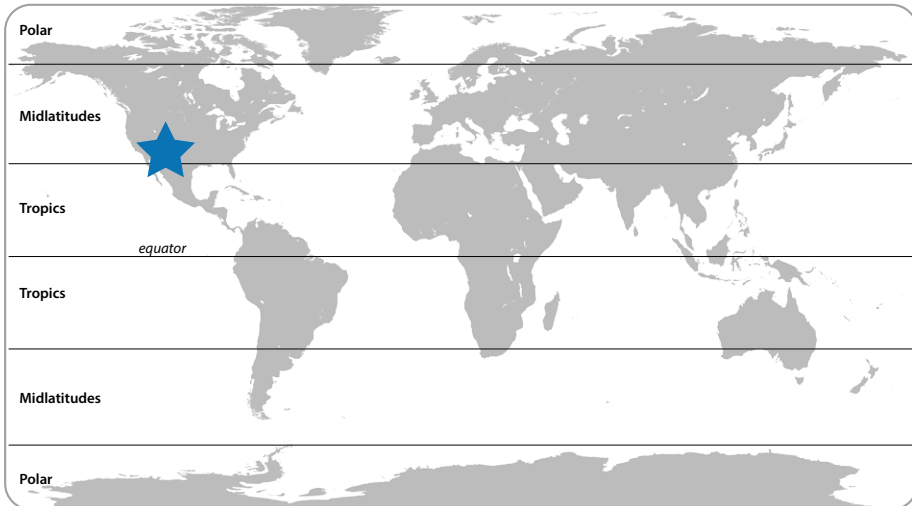


Location:
Arizona, US

Latitude:
36.4493

Distance from
the equator:
4,046 km

M





UCAR CENTER FOR
SCIENCE EDUCATION

TEACHER GUIDE

TEACHER GUIDE



CULMINATING TASK

CULMINATING TASK: **Challenge 1**

CALIFORNIA STORM

CULMINATING TASK: **Challenge 2**

WHERE'S THE SNOW?

CULMINATING TASK: **Challenge 3**

WE'RE WARNING YOU

Snow Day?

How can we apply what we've learned about weather to a winter storm?



Students apply models and ideas they figured out from Learning Sequences 1, 2, and 3 to explain what is happening with a new phenomenon: a winter storm that crossed the United States in February 2017. Students should make connections between the dynamics of the atmosphere that they learned about in Learning Sequence 1 (how the atmosphere cools with altitude, how humidity is needed for precipitation, and how rising air cools and moisture condenses), the characteristics of a cold front that they learned about in Learning Sequence 2 (how a cold air mass pushes into a warmer air mass, causing it to rise higher in the atmosphere and how areas with low pressure are prone to have precipitation), and global-scale processes that they learned about in Learning Sequence 3 (such as prevailing winds in the midlatitudes moving from west to east).

The storm presented in the Culminating Task is intentionally different from the storms in the learning sequences, giving students the opportunity to apply what they have learned in a new context. This storm is another example of how weather can impact people's lives. Students work in groups to understand what's happening in the storm using what they've learned in GLOBE Weather and applying it to answer questions about this storm. Looking at the history of snowfall from the storm over several days, the path of the storm, and warning information, students make a decision about where schools and businesses will likely close due to snow and ice.

SCIENCE IDEAS


Weather in a given area is based on geographic location (i.e., latitude, altitude, and geographic features) and changing atmospheric conditions (i.e., air temperature, humidity, air masses, fronts, atmospheric pressure, prevailing winds, and global atmospheric circulation). Weather impacts people's lives and the communities in which they live in different ways. Winter storms affect transportation, safety, economics, and recreational activities.

CULMINATING TASK: Challenge 1

California Storm

Why did the storm cause rain in some places and snow in other places in California?

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes)	
<p>Introduction to the Winter Storm Students view a video of a new phenomenon, winter storm Quid, and observe the storm.</p>	<p>Challenge 1: Student Activity Sheet  Winter storm Quid video: (https://scied.ucar.edu/video/winter-storm-quid)</p>
<p>Challenge 1: California Storm Students explain what caused this storm to bring precipitation in California and why precipitation is different at South Lake Tahoe and Heavenly Mountain, drawing on ideas from Learning Sequences 1, 2, and 3. Students work in small groups to develop explanations. They then share their ideas with the class and come to consensus.</p>	<p>Model Idea Tracker, Consensus Models</p>



NGSS Sensemaking

In Challenge 1, students use models developed in Learning Sequences 1, 2, and 3 to explain where the moisture in this winter storm came from, how the storm is moving and why, and why precipitation is snow in one location and rain in another.

NGSS DIMENSIONS (GRADES 6-8)

- Apply scientific ideas to construct an explanation for real-world phenomena or events.
- Weather is influenced by interactions involving sunlight, the ocean, and the atmosphere. These interactions vary with latitude, altitude, and regional geography, all of which can affect atmospheric flow patterns.

Teacher Procedures

Introduction to the Winter Storm

- 1. Introduce students to the winter storm.** Tell students that they will be investigating a winter storm and that they should draw on ideas from Learning Sequences 1, 2, and 3 to predict the storm's path. Once we know the storm's path, we can warn people who will be affected. Show students a video, which forecasts how this winter storm could affect the Midwest.

WINTER STORM QUID WEATHER FORECAST



[This short video](#) from the Weather Channel gives a sense of what the storm was shaping up to be as it crossed the United States in February 2017. (Note: The Weather Channel names winter storms. This one was named Quid. Credit: the Weather Channel) (<https://scied.ucar.edu/video/winter-storm-quid>)

- 2. Introduce the three challenges that are part of the Culminating Task.** Explain to students that they will work in groups of two or three to understand this winter storm as it moved from California to the Rockies to then predict how it will affect the Midwest.

Their tasks are:

1. Understand factors that increase the chances of precipitation.
2. Predict which communities in the storm's path in the Midwest should prepare for heavy snow and take safety precautions.

Challenge 1: California Storm

- 1. Motivate a purpose for Challenge 1.** Tell students that when the storm was in California, heavy rain fell in some areas and heavy snow fell in other areas. Explain that students will need to figure out why that happened and also where the storm came from and where it is going.

CT
Challenge
1

STEP 1

- 2. Introduce Challenge 1.** Pass out the *Challenge 1: Student Activity Sheet* and orient students to the map, which shows a zoomed-out box of the area where the storm hit (the symbols on the map should be familiar to students at this point, review as needed). Together, read the introduction addressing where it rained along the West Coast on February 20, 2017.
- 3. Prepare students to work on Challenge 1.** Arrange students in partners or groups of three (students will work in the same groups throughout all three challenges of the Culminating Task). Display the class Consensus Models developed during Learning Sequences 1, 2, and 3 as well as the Model Idea Tracker. Tell students they can use these ideas and models to help them with the challenge.
- 4. Work on Challenge 1 in small groups.** Give students time to answer the questions in *Challenge 1: Step 1* about the California storm. As students work, circulate the groups and prompt students to draw on previous models and Model Ideas.

- *What is the direction of prevailing winds across North America?*
- *How can you use the symbol for a cold front to figure out the front's direction?*



Storyline Link

Remind students of the destruction they saw with the Colorado storm and that understanding how storms form and where they move can help us prepare communities in their paths.



Developing & Using Models

Student models from Learning Sequences 1, 2 and 3 should help students develop explanations for where the storm came from and where it's heading.

CT
Challenge
1
STEP 2

5. **Draw student attention to Challenge 1: Step 2, which provides more detail about the California storm.** The new information details South Lake Tahoe experiencing rain while Heavenly Mountain experiences snow. Give students time to answer the Step 2 questions with their group. Encourage students to sketch on the cross section what is happening in the air at South Lake Tahoe compared with Heavenly Mountain. Introduce the idea that as the weather transitions from rain to snow there will likely be an area that experiences a rain-snow mixture. Student answers about where the rain-snow mixture might have happened will vary. There is not enough data for them to pinpoint exactly where that happens, but they should understand that it will happen somewhere between the town and the mountaintop.
 - *What do we know about temperatures at lower and higher altitude?*
 - *How might air temperature at the Heavenly summit be different from air temperature at South Lake Tahoe?*
6. **Share initial ideas with another group.** Have students share their ideas about Steps 1 and 2 in Challenge 1 with another small group. Give students time to edit and add to their explanations as they share and discuss similarities and differences between their initial responses to the questions.
7. **Discuss Challenge 1 questions as a whole class.** Focus on coming to consensus about each question and recording the consensus explanation for the class. Students can continue to edit their ideas if they hear something new or different they'd like to add. Have students share their images of what is happening on a document camera to support their explanations.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>Where do you think the cold front was located before it passed over California?</i>	<ul style="list-style-type: none"> • It's moving from west to east, according to global circulation, which means it was over the Pacific Ocean.
<i>Where do you think the moisture that's in this storm came from before it was in the atmosphere?</i>	<ul style="list-style-type: none"> • It evaporated from the Pacific Ocean. (Some water evaporated from Lake Tahoe, but it was a small amount compared with the amount that evaporated from the ocean.)
<i>Where do you think the storm will go next?</i>	<ul style="list-style-type: none"> • Surface winds blow west to east at the midlatitudes, so this storm should move east due to these winds. • The cold front symbol has the triangles pointing toward the east, so that is the direction the storm is moving.



Developing & Using Models

Student explorations of the Virtual Ballooning interactive in Learning Sequence 1 will help them with the question of rain versus snow. Students may need help connecting what they learned about temperature and altitude with formation of snowflakes (i.e., that the temperature needs to be below freezing for snowflakes to form).



Assessment

Listen to student responses to the Challenge question and/or read their explanations on the Exit Tickets to give you clues about how students are leveraging science ideas from the previous lessons.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<p><i>Why did it snow at Heavenly Mountain and rain in South Lake Tahoe?</i></p>	<ul style="list-style-type: none"> • The air temperature is cooler higher in the troposphere. We know that from the Virtual Ballooning investigation. So, it should be colder at Heavenly, which is a higher altitude than South Lake Tahoe. This means it would snow at Heavenly if the temperature is freezing. • Both locations are at high altitude, but Heavenly is much higher, and it must be below freezing.
<p><i>If you were to decide whether rain or snow will fall during a storm, what information would you look at and why?</i></p>	<ul style="list-style-type: none"> • You would look at air temperature because if it is a certain temperature, the water will freeze to snow.

8. **Return to the Challenge 1 question.** Revisit the question: “Why did the storm cause rain in some places and snow in other places in California?” Have students discuss an explanation to this question in groups and/or write a response on an Exit Ticket before the end of the lesson.

CULMINATING TASK: Challenge 2

WHERE'S THE SNOW?

As the storm moved east, why did it snow in some areas but not others?

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes)	
<p>Challenge 2: Where's the Snow? Students examine data as the winter storm moves east across the western interior. They explain why this storm brought precipitation to some locations but not others, drawing on ideas from previous lessons. Students work in small groups to develop explanations. They then share their ideas with the class and come to consensus.</p>	<p>Challenge 2: Student Activity Sheet</p> <p>CULMINATING TASK: Challenge 2</p> <p>Colored pencils</p>



NGSS Sensemaking

In Challenge 2, students use models developed in Learning Sequences 1, 2, and 3 to explain why some areas in the Rockies got a lot of snow and others did not. Students identify that heavy precipitation is located near an area of low pressure where moist air rises and becomes available for precipitation.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Weather is influenced by interactions involving sunlight, the ocean, and the atmosphere. These interactions vary with latitude, altitude, and regional geography, all of which can affect atmospheric flow patterns.
- Apply scientific ideas to construct an explanation for real-world phenomena or events.
- Charts can be used to identify patterns in data.

Teacher Procedures

Challenge 2: Where's the Snow?



1. **Navigate from the previous lesson.** Review what students learned about winter storm Quid in Challenge 1 and revisit the two questions that ended the previous challenge:
 - *What information would you need to decide whether rain or snow will fall during a storm?*
 - *Where is the storm heading next and how do you know?*

Listen for the following responses:

- You need to look at temperature. If it's colder in the atmosphere, it will snow.
 - This winter storm will move east because of prevailing surface winds in the midlatitudes.
2. **Discuss where the winter storm is heading.** Project the class map for Challenge 2 and explain that in Challenge 2 students will analyze precipitation data for the winter storm three days after it was in California. The storm is now located in the Rocky Mountains. Their goal is to identify places with heavy precipitation and decide what is causing precipitation in this area.
 3. **Prepare to complete Challenge 2.** Pass out the *Challenge 2: Student Activity Sheet*. Read the instructions together for Challenge 2 and outline the four steps students will complete. Orient students to what is shown on the map over the four days of the storm. Have students return to their groups/partners from the previous day. Remind students to use their class Consensus Models and Model Idea Tracker to help them decide what is happening to cause heavy precipitation.
 4. **Work on Challenge 2 in small groups.** Give students 20 minutes to work on *Challenge 2: Steps 1-4*. In *Step 1*, students will write the snowfall totals from the data table on their map and identify the communities that had significant snow. In *Step 2*, students use the snowfall map to predict where schools might close. For *Step 3*, students consider patterns in snowfall and why some areas had more snow than others. *Step 4* reminds students of the two things needed for precipitation (rising, cooling air and humidity). Students draw air movement and cloud formation in the cross sections showing low pressure and the front and relate distance from the storm to the amount of snowfall received. *Step 4* continues with students completing the humidity map and determining which locations didn't have enough moisture to result in a storm.

As students work, circulate the groups and prompt students to draw on previous models and Model Ideas.

- *Think about how precipitation forms around a front. What's happening to the air along the front?*
 - *What happens to air in a low-pressure area?*
 - *Even though a cold front is passing through all these towns, why might some not get any precipitation? What's an important ingredient that could be missing?*
5. **Discuss Challenge 2 questions as a whole class.** Project the map for Challenge 2 and discuss the following question prompts. Focus on coming to consensus about each question and recording the consensus explanation for the class. Students can continue to edit their answers from *Steps 1-4* if they hear something new or different they'd like to add. Have students share their images of what is happening on a document camera to support their explanations.



Storyline Link

In the previous challenge, students explained that temperature was important for determining precipitation and the storm was heading east.



Developing & Using Models

Student models from Learning Sequences 1 and 2 should help students develop explanations for why it snowed in some places but not others.



Patterns in Data

Students identify patterns in the data tables, looking for relationships between places with heavy snow and average humidity.



SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>Where were the communities with heavy snowfall located in relation to the storm?</i>	<ul style="list-style-type: none"> • These locations are near or just behind the area of low pressure at the northern end of the cold front.
<i>Explain why places like Cortez, Gallup, and Albuquerque didn't get any snowfall at all.</i>	<ul style="list-style-type: none"> • They are not close enough to the low pressure area, which is necessary for warmer, moist air to rise up into the atmosphere.
<i>Did it always snow in areas that had high humidity? Explain why or why not. Give examples.</i>	<ul style="list-style-type: none"> • Devils Tower is the only location that had high humidity but absolutely no snow. Since it is the farthest from the low-pressure system, there was no mechanism for the moisture to rise up into the atmosphere. In general, areas with high snowfall did indeed also have high humidity.
<i>Compare the two areas with the highest snowfall to the two areas with the highest humidity.</i>	<ul style="list-style-type: none"> • The areas with the highest snowfall did indeed have high humidity, but the areas with the highest humidity didn't happen to have all that much snow due to the large distance between them and the storm.
<i>Why do some communities have more snowfall than others? What is happening to air in these areas?</i>	<ul style="list-style-type: none"> • Areas of low pressure have warm, rising air with moisture. This means there is more moisture rising in this area, so there is a higher potential for more precipitation. (Students' Step 4 drawings may vary but should indicate that an area of low pressure is where warm air, or relatively warm air, with moisture is rising and then cooling to create storms and precipitation.)
<i>Why didn't it snow everywhere?</i>	<ul style="list-style-type: none"> • Some of the places where it didn't snow were too far from the storm. • Some of the places where it didn't snow had low humidity. That means they didn't have enough moisture in the air for it to snow.
<i>Where might schools close?</i>	<ul style="list-style-type: none"> • Students' answers may vary but should include all locations with significant snow (Rock Springs, WY; Dinosaur, CO; Vernal, UT). Students may include locations with less snow depending on their experience with snowstorms and school cancelations. (Students will learn more about safety and cancelations in Challenge 3.)



Assessment

Listen to student responses to the Challenge question and/or read their explanation on the Exit Tickets. See if students identify rising, moist air in the area of low pressure as a key factor in the heavy snow.

6. **Return to the Challenge 2 question.** Revisit the question: "As the storm moved east, why did it snow in some areas but not others?" Have students discuss an explanation to this question in groups and/or write a response on an Exit Ticket before the end of the lesson.

CULMINATING TASK: Challenge 3

WE'RE WARNING YOU

Where will schools have a snow day on February 24th?

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes)	
<p>Challenge 3: We're Warning You</p> <p>Students draw on ideas from Challenges 1 and 2 as well as their class Consensus Models to predict where snow will fall next as Quid moves toward the Midwest. Students work in small groups to develop predictions for the location of heavy snowfall. They share their predictions with the class. They review storm warning information and read a text about storm warning systems. Using this information, students revise their predictions. Students consider how what they've learned in the unit can prepare them for severe weather in their area.</p>	<p>Challenge 3: Student Activity Sheet</p> <p>CULMINATING TASK: Challenge 3</p> <p>Color copies of the warning map (or access to the map on a computer/tablet)</p> <p>Model Idea Tracker, Consensus Models</p> <p>Driving Question Board</p>



NGSS Sensemaking

In Challenge 3, students use models developed in Learning Sequences 1, 2, and 3 to predict what areas in the Midwest can expect a lot of snow. Students reflect on the questions they asked at the start of the unit and what they know now. Students then construct an explanation about a specific precipitation event in their community demonstrating what they've learned about the unit driving question.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Weather is influenced by interactions involving sunlight and the atmosphere. These interactions vary with latitude, altitude, and regional geography, all of which can affect atmospheric flow patterns. Because these patterns are so complex, weather can only be predicted probabilistically.
- Use a model to predict phenomena.

NGSS DIMENSIONS (GRADES 3-5)(REINFORCING)

- Patterns of change can be used to make predictions.

Teacher Procedures

Challenge 3: We're Warning You

1. **Navigate from the previous lesson.** Review what students learned about this winter storm in Challenge 2. Focus the review discussion on the questions that ended the previous challenge:
 - *How do we know where it will snow? What's happening to the air in this area?*
 - *Where is the storm heading next, and how do you know?*

Listen for the following responses:

- It will snow in places near the front that have sufficient moisture. Most of these places are near the area of low pressure because there is more rising moisture here.
 - This winter storm will move east because of prevailing surface winds in the midlatitudes.
2. **Introduce Challenge 3.** Project the class map for Challenge 3 and explain that students will take what they know about this winter storm on February 23, 2017 and make a prediction about which locations will be in the path of the storm on February 24, 2017. Explain that weather predictions are often made to help keep people safe. Introduce how winter storms can prove hazardous (e.g., blowing snow can reduce visibility on the roads, ice can cause people to slip while walking and have auto accidents). Challenge students to identify which communities need to consider closing schools and businesses to stay safe. (Note: As you introduce the class map, students may notice that the front and low-pressure areas are moving at different rates than they were a few days before. It's not uncommon for a storm system's rate of movement to change.)
 3. **Prepare to complete Challenge 3.** Pass out the *Challenge 3: Student Activity Sheet*. Have students return to their groups/partners from the previous day. Have students take out the class Consensus Models and their Model Idea Tracker. Tell students they can draw on these ideas and models to help them with the challenge.



STEP 1-3

4. **Work on Challenge 3 in small groups.** Give students 20 minutes to work on *Steps 1-3* in Challenge 3. Have students make predictions about where it will snow on February 24, 2017 based on characteristics of the storm on February 23, 2017. As students work, circulate the groups and prompt students to draw on previous models and Model Ideas.
 - *In Challenge 2, what was the air pressure like in places where heavy amounts of snow fell? [low]*
 - *What was happening to the air in this area?[it was rising]*
 - *What side(s) of the low-pressure area did the snow fall in Challenge 2? [on the north and west sides]*
5. **Discuss Challenge 3 questions as a whole class.** Project the map for Challenge 3 and discuss question prompts from *Steps 1, 2, and 3*. Students do not need to come to consensus on their predictions yet.



Storyline Link

In this lesson, students draw on observations from Challenge 2 and their models to predict where snow will fall as the storm moves east.



Developing & Using Models

Students compare similarities and differences with this winter storm to the model they developed in Learning Sequence 2 to explain precipitation along a cold front.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>Where did it snow on February 23, 2017? Compare the locations with snow to the location of the front and low-pressure area.</i>	<ul style="list-style-type: none"> It snowed in places just behind the area of low pressure and at the northern end of the cold front.
<i>Where do you think will it snow on February 24, 2017 and why?</i>	<ul style="list-style-type: none"> It will likely snow in places like Des Moines, IA and Madison, WI that are behind the low pressure area and to the north of it.



6. **Read the warning map and snow day text in Step 4.** Explain that these are the areas where warnings were issued as places that may be vulnerable to severe weather on February 24, 2017. Have students read the warning map and text: Is it a snow day? Students answer the question at the end of the text on their own.

- What locations should cancel school based on the reading above and your predictions of snowfall from Step 3?*

NOTE: Students need to view the warning map in color. Consider making a class set of color print outs for repeated use or plan to have students use a computer or tablet to view the map in color. The warning map is also included in the slide set.



7. Discuss and revise predictions with the class in **Step 5.** Tell students that scientists, including meteorologists, revise their predictions once they have more information. Have students revise their predictions for February 24, 2017 to take into account the warning information and text. Discuss and revise predictions about where it will snow on February 24, 2017.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>Where will it snow on February 24, 2017 and why?</i>	<ul style="list-style-type: none"> It will snow in places like Des Moines, IA and Madison, WI that are behind the low-pressure area and to the north of it.

8. **Conclude the discussion and focus on preparing for severe weather in your area.**

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<p><i>What types of weather hazards do we face that can close schools, businesses, or roads in our area?</i></p> <p><i>How could what we learned in this unit help us prepare for severe weather in our area?</i></p>	<ul style="list-style-type: none"> Answers will vary (e.g., flooding, tornadoes, ice on the roads). Answers will vary (e.g., it helps us know what's causing the heavy precipitation; it helps us know why some places get more precipitation than others).



Construct an Explanation

Ask students to use their models to help them construct an explanation about a specific kind of precipitation event in their community. This activity can be used as an assessment of learning.

9. **Return to the unit driving question: "What do we know about storms?"** Ask students to think of one type of precipitation event in their local area. It can be an isolated storm, a front, or a different precipitation pattern. Ask students to explain as much as they can about why they think this storm happened. This activity can occur as a class discussion and/or an individual writing task, followed by small group sharing of ideas.
10. **Return to the Driving Question Board to answer any lingering questions.** Ask students to revisit the Driving Question Board to answer any questions. There may be several questions remaining on the board that were not answered in the course of the unit. Consider having students take responsibility for researching one question from the board and reporting what they learned back to the class.
11. **Wrap up the *GLOBE Weather* unit.** Have students brainstorm answers to the question: "How can we use what we've learned about weather?" There are many correct answers to this question, so encourage students to be creative. Student answers may be individual (e.g., "Now we know what the meteorologist on TV is talking about.") or larger and more involved (e.g., "Now we can collect our own weather data or research what types of storms happen where we live.").



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STUDENT ACTIVITY SHEETS

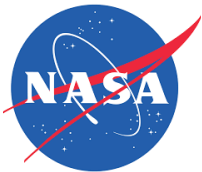


THE GLOBE PROGRAM





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LESSON 1



WHAT DO WE KNOW ABOUT STORMS?



THE GLOBE PROGRAM

 LESSON 1

What do we know about storms?

**STEP 1: What happens in the atmosphere to cause a storm?**

Your class will watch a video about a storm that happened in Colorado and how the precipitation affected the city of Boulder, Colorado. After watching the video, think about what you know about the water cycle and how storms form. What do you think happens in the atmosphere to cause rain, snow, and other types of precipitation? Write your ideas below.

STEP 2: What are my experiences with storms and precipitation?

Think about a time when you experienced a storm. Answer the questions below.

1. Was it a rainstorm, a snowstorm, or some other type of storm?
2. What time of year did it happen?
3. Did the storm last for a few hours or a day or more?
4. How did the precipitation from this storm affect your community?

What do we know about storms?

**STEP 3: Represent what you know about storms.**

What caused the rain in the Colorado storm you saw in the video? Draw and label a picture in the box below to answer this question. Your picture is a model of how this storm happened.

- Your picture should show all the factors that led to rain.
- Include labels in your drawing that explain how each factor led to rain.
- Be prepared to share your thinking with the class.



LESSON 1

What do we know about storms?



STEP 4: How were my ideas similar or different from my peers' ideas?

Describe your model to the other students in your group.

SIMILAR IDEAS	DIFFERENT IDEAS

STEP 5: What questions do I have about storms and precipitation?

What do you wonder about how storms form? List questions that you have about storms and precipitation.

CONGRATULATIONS,

you are now part of the GLOBE community!

Now that you have completed Lesson 1 of GLOBE Weather, you are ready to be an active GLOBE student scientist.



GLOBE stands for **G**lobal **L**earning and **O**bservations to **B**enefit the **E**nvironment. GLOBE is an international science and education program that includes students and scientists from all over the world. You now have the opportunity to participate in GLOBE along with other students interested in learning more about the environment through conducting research on topics that are interesting to you. GLOBE has many resources and opportunities for scientists of all ages. Check out how to get involved by viewing a short video (4:26 minutes) on the GLOBE website: <https://www.globe.gov/do-globe/for-students/be-a-scientist>.



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LEARNING SEQUENCE 1

LESSON
2

WHAT CAUSES STORMS TO FORM?

LESSON
3

**HOW DOES TEMPERATURE RELATE TO CLOUD
FORMATION?**

LESSON
4

**WHAT IS DIFFERENT ABOUT A SUNNY DAY AND A
STORMY DAY?**

LESSON
5

**HOW DOES AIR MOVE AND CHANGE WHEN A STORM IS
FORMING?**

LESSON
6

CAN WE IDENTIFY THE BEST CONDITIONS FOR STORMS?

LESSON
2

What causes storms to form?

WATCHING CLOUD SHAPES AND HOW THEY CHANGE OVER TIME CAN GIVE YOU CLUES ABOUT WHAT'S HAPPENING IN THE SKY.



STEP 1: What can we learn about storms by watching clouds in the sky?


Working in pairs or small groups, write your ideas below. (Use complete sentences.)



STEP 2: What do you notice about the sunny day compared to the stormy day?

Observe the clouds in the time-lapse videos and record your observations below.

 **SUNNY DAY**

 **STORMY DAY**

Why do you think that the storm formed on one day and not the other?

Write your ideas below, using complete sentences.

What causes storms to form?



STEP 3: Draw how a storm forms throughout the day.

Think about the time-lapse video of a stormy day. Draw what the weather is like at different times throughout the day, using each of the boxes below. Include what you know about how clouds, water, air, and sunshine move and change throughout the day.

MORNING 9:00AM

MID-DAY 12:00PM

AFTERNOON 3:00PM

NIGHTTIME 9:00PM

What causes storms to form?



STOP AND THINK

Answer the questions below.

Clouds and storms are typically high above the ground. If you could investigate the air up high compared to the air near the ground, what do you think you would notice?

What measurements about the air would you want to take from different altitudes?

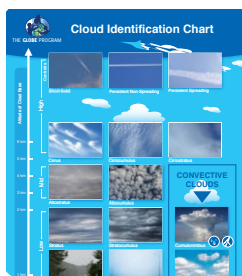
How might those measurements help us figure out how clouds form?

STEP 4: Make observations of clouds in the sky!

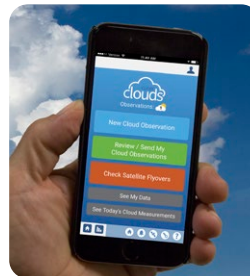
Watch the sky for clues about what's happening with weather in your community. Follow your teacher's instructions for making observations and remember **to never look directly at the Sun**.

Remember to look for:

- How much of the sky is covered with clouds?
- What types of clouds are in the sky?
- Are the clouds opaque or can you see through them?



Identify clouds using the [GLOBE Cloud Chart](http://globe.gov/globecloudchart) (globe.gov/globecloudchart)



Download the [GLOBE Observer Clouds App](http://observer.globe.gov) (observer.globe.gov) to make cloud observations and take pictures that can be compared with NASA satellite images. This helps scientists understand the sky from above and below.

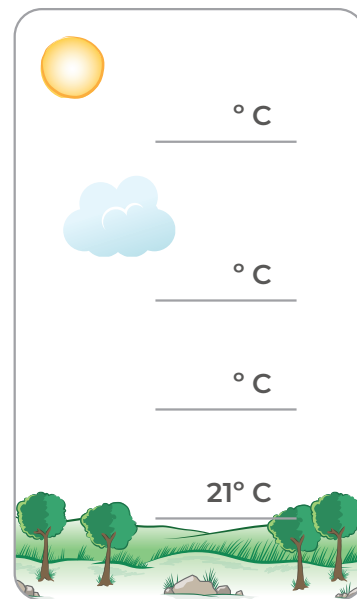
LESSON
3

How does temperature relate to cloud formation?

Weather balloons carry instruments into the atmosphere to collect temperature data at different altitudes – from near the ground to up where clouds form and even higher. In this lesson you'll explore data collected by a weather balloon to learn about how air changes with altitude.

**STEP 1: Use the temperature near the ground to predict the other temperatures.**

Fill in the blanks in the graphic at the right to make a prediction about how air temperature changes with altitude.

**STEP 2: Collect temperature data.**

At a computer or tablet, open the Virtual Ballooning interactive (scied.ucar.edu/virtual-ballooning). With this simulation you can launch virtual weather balloons and record the temperature at different altitudes in the atmosphere.

1. Click **"Explore the Troposphere"** to get into the game.
2. **Get to know the graph.** Notice that altitude is on the vertical axis (the y-axis) and temperature is on the horizontal axis (the x-axis).
3. **Choose settings for a balloon launch.** Each balloon you launch will make three measurements of temperature. Set the altitude to start recording the temperature by dragging the **"Collect Data"** arrow up or down the y-axis.
4. Click the **"Launch Balloon"** button and watch as your balloon collects temperature data.
5. **Record that temperature in the table on the next page.** Read the points that the balloon made on the graph to find the temperature at different altitudes.
6. Click the **"New Flight"** button and choose new settings for another balloon launch to collect more data. Collect as much data as you can with four balloon launches.



How does temperature relate to cloud formation?

STEP 2 CONTINUED:

Collect temperature data.

	ALTITUDE	TEMPERATURE (°C)
↑ high clouds low clouds ↓	10 km	
	9 km	
	8 km	
	7 km	
	6 km	
	5 km	
	4 km	
	3 km	
	2 km	
	1 km	
0 km		

Step 3: Analyze and interpret the data.

1. Describe the pattern you see in the temperature data from the ground to where storm clouds form.
2. Is this the pattern you predicted? Why or why not?
3. What do you think is *causing* the temperature pattern?
4. How does the temperature pattern relate to storms forming?
(Draw or write your ideas below.)



How does temperature relate to cloud formation?

STEP 4: How do air and surface temperatures change during a day?

To learn why air temperature changes with altitude, take a look at how the temperature of the ground (surface temperature) relates to the temperature of the air just above the ground (air temperature) in the graph below. Students at Westview Middle School in Longmont, Colorado, collected the data in this graph. Every hour during a day they measured surface temperature and air temperature outside their school.

Compare the two data trends in the graph by following these directions:



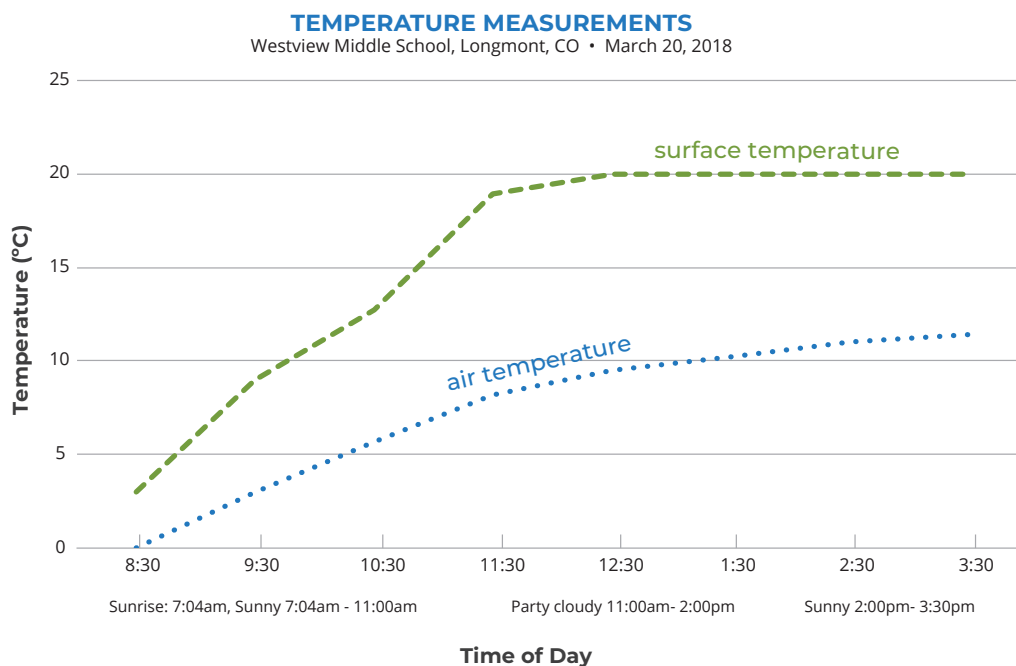
WHAT I SEE

1. Look at different parts of the graph. Do you notice patterns? Do you notice interesting differences? Write **What I See** statements on the graph to record your observations.
2. Share your statements when directed by your teacher.



WHAT IT MEANS

1. Next to each **What I See** statement, write a **What It Means** statement to explain what you think is happening in each part of the graph.
2. Share your statements when directed by your teacher.



Write a caption for the graph that compares the two data trends.



How does temperature relate to cloud formation?

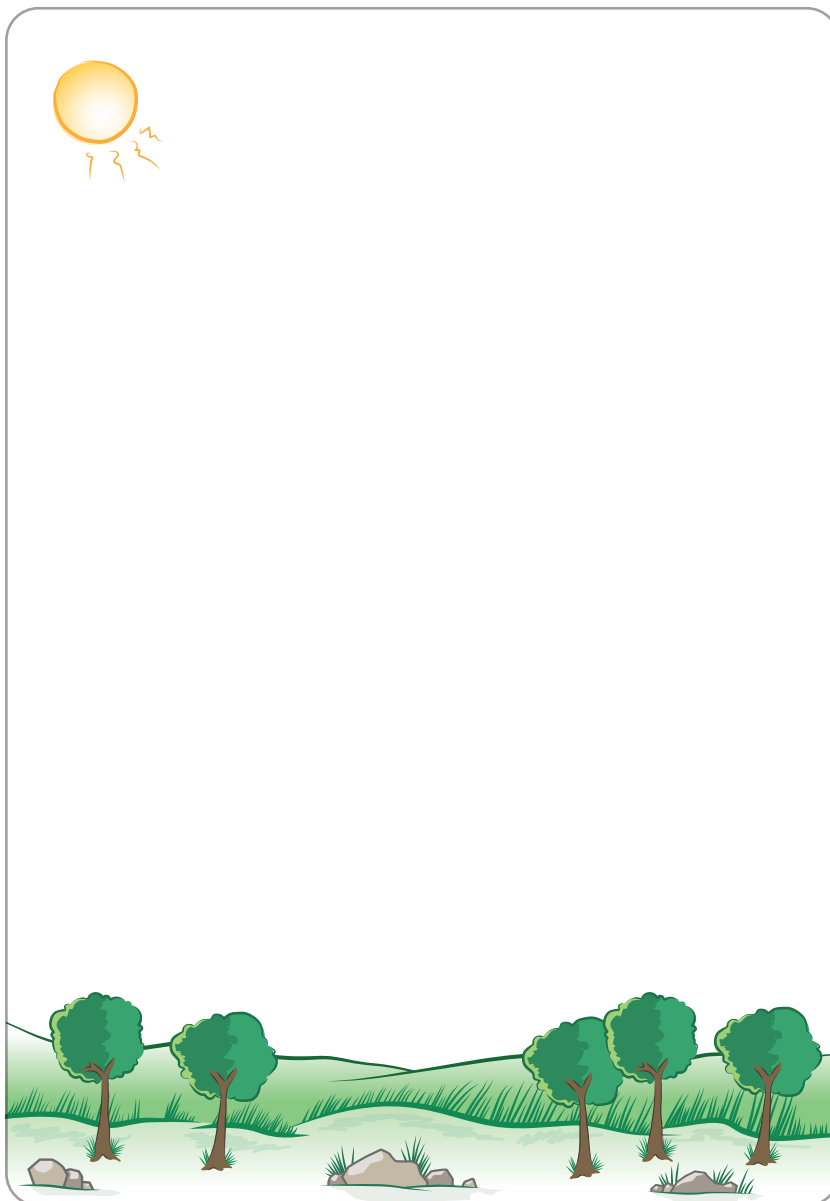
STEP 5: Make a model of how sunlight warms the atmosphere.

Draw a model in the box below that helps to answer the following question:

Why does the surface temperature warm over the day, and why is the surface warmer than the air above it?

Your model should explain:

- How surface temperature is related to the sunlight
- How air temperature is related to surface temperature
- How the air temperature changes from the ground to higher altitudes
- How you know the above three things using evidence from temperature data



KEY
(Choose colors to represent sunlight and temperature.)

sunlight

temperature

Write a caption for your model that describes how sunlight warms the atmosphere.



How does temperature relate to cloud formation?

STEP 6: How does your model relate to storms?

There wasn't a storm on the day when the Westview Middle School students collected surface temperature and air temperature data, but it did get cloudy in the afternoon.

The time-lapse video showed that clouds started to build in the morning and by afternoon there was rain.

Write a sentence to answer the question: How do you think temperature relates to the clouds and storm forming?

List evidence from your model to support your answer above.

Describe the reason that the evidence you listed supports your answer.



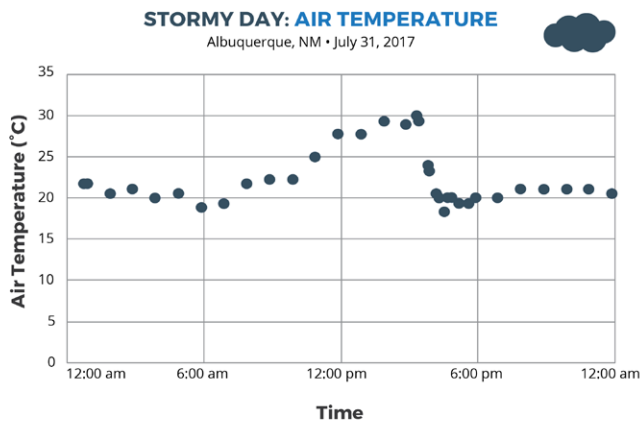
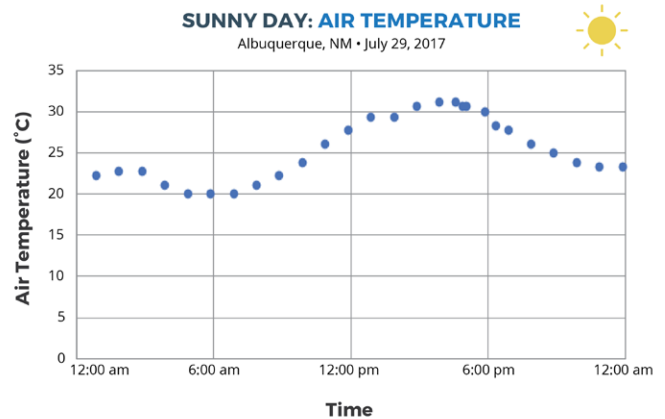
LESSON 4

What is different about a sunny day and a stormy day?

STEP 1: Compare air temperatures on a sunny day and a stormy day.

Do stormy days have a different pattern than sunny days? Answer the questions using the graphs of temperature data below.

1. Describe the sunny day pattern.



2. Describe the stormy day pattern.

3. Looking only at the temperature data, when do you think the rain happened, and why? Circle where the rain begins on the stormy day graph.

What is different about a sunny day and a stormy day?

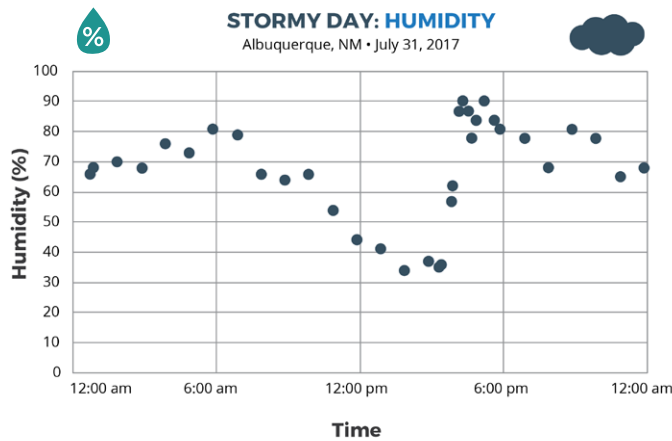
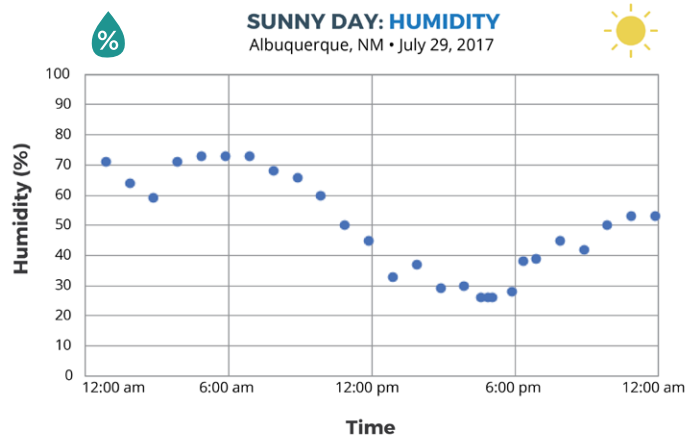


STEP 2: Compare the humidity on a sunny day and a stormy day.

Humidity is the amount of water vapor in the air. If the humidity is 100%, then the air cannot take in any more water vapor (and you are probably in a cloud). If the humidity is less than 100%, then the air could take in more water vapor. Warm air has the energy needed to evaporate more water than cold air. That's why a hot and humid day is more common than a cold and humid day. When humidity is low, people say that the air is dry because it doesn't have much water vapor.

Do stormy days have a different pattern than sunny days? Answer the questions using the graphs of humidity data below.

1. Describe the sunny day pattern.



2. Describe the stormy day pattern.

3. Circle where the rain begins on the stormy day graph. Considering both air temperature and humidity, what pattern do you think creates the highest chance for storms to form?

What is different about a sunny day and a stormy day?



STEP 3: Make a storm in a bottle.

Using what you know about temperature and relative humidity, create a model of a sunny day and a stormy day using clear bottles with different contents.

1. Draw what you put inside each of your bottles. Label the materials that you added.





2. Turn on the lamp (to represent the Sun) and observe the bottles for 20 minutes. Add your observations about the temperature and humidity of each bottle to the pictures above. Use the data table on the next page to record temperature and humidity changes in your bottles.
3. **Discuss the following questions with your peers:**
 - Did the sunny day bottle match what you expected? If not, what happened?
 - Did the stormy day bottle match what you expected? If not, what happened?
 - Using evidence from the bottles and the temperature and humidity data, what conditions are best for storms?

What is different about a sunny day and a stormy day?



Measure the temperature with your thermometer and record. Look for evidence of humidity, such as condensation on the inside of the bottle, and make notes about it in the table below.

SUNNY DAY BOTTLE 		STORMY DAY BOTTLE 		
MINUTE	TEMPERATURE (°C)	HUMIDITY	TEMPERATURE (°C)	HUMIDITY
2				
4				
6				
8				
10				
12				
14				
16				
18				
20				



3. Discuss the following questions with your peers:

- Did the sunny day bottle match what you expected? If not, what happened?
- Did the stormy day bottle match what you expected? If not, what happened?
- Using evidence from the bottles and the temperature and humidity data, what conditions are best for storms?

LESSON
5

How does air move and change when a storm is forming?

Your teacher will demonstrate how air changes as it is heated or cooled. This will help you figure out what happens to air that warms near the surface, and air that cools at higher altitudes.

STEP 1: Observe warmed and cooled air.

Draw the lab set-up and what happens to the balloon during the demonstration. Add your observations to your drawing as you make them. Remember to label what is happening.

LAB SET-UP	MYLAR BALLOON BEING HEATED	MYLAR BALLOON AS IT COOLS

1. Why does the heated balloon go up? Think about what is happening inside the balloon.

2. What is happening inside the balloon when the balloon starts to sink?

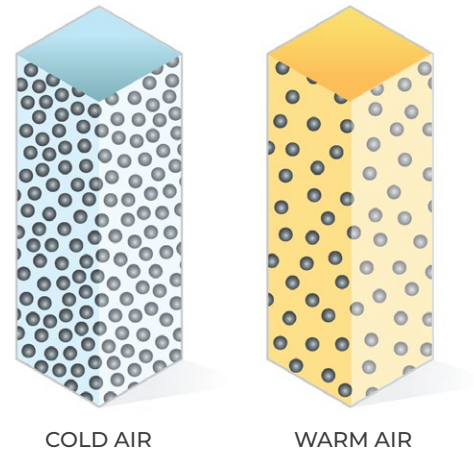


How does air move and change when a storm is forming?

STEP 2: Air on the Move

There is something different between warm and cool air that causes warm air to go up and cool air to go down. When the air inside the balloon was warmed, the balloon expanded and went up. When the air inside the balloon cooled, the balloon started to shrink and go down. Let's think a little more about this air and what is happening when it is warmed and cooled. To understand this, we are going to need to zoom in and think about what's happening to the air molecules.

Imagine you can see a pocket of air molecules heated up. When air is heated, the heat energy is absorbed by the individual molecules, causing them to move around more quickly. The molecules move faster and farther apart. When molecules release their energy, they start to slow down and cluster closer together. This happens when the molecules no longer have a heat source and are "cooling."



Draw a diagram that shows what 20 warmed air molecules look like inside the mylar balloon compared to 20 cooler air molecules.

BALLOON WITH WARM AIR	BALLOON WITH COOL AIR

So, that's how warm air and cool air are different. But why do they move in different directions? To understand that, we're going to need to zoom out and think about the whole planet and gravity.



How does air move and change when a storm is forming?

STEP 2 CONTINUED: Air on the Move

Gravity is the force that draws all objects towards the center of the planet. Even tiny things like air molecules are affected by gravity and pulled downward. The weight of the air molecules higher in the atmosphere pushes air molecules lower in the atmosphere closer together. High in the atmosphere, they are spaced farther apart. Air molecules pushed close together are at high pressure. Air molecules spread apart are at low pressure.

Draw air molecules between the planet and the top of the atmosphere. Remember that they will be spaced differently depending on whether they are close to the ground or higher in the atmosphere.



How does air move and change when a storm is forming?

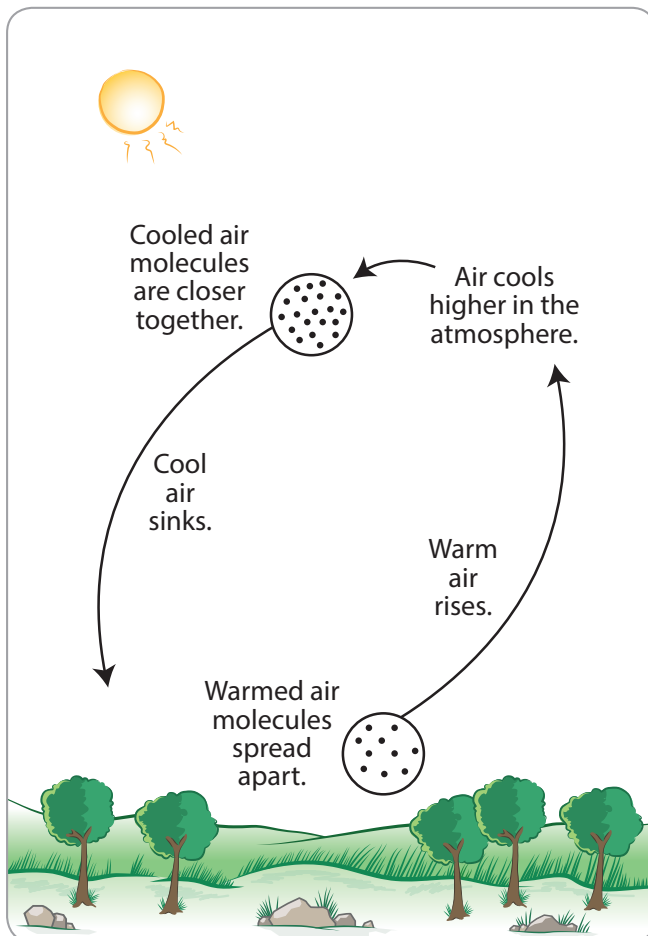
STEP 2 CONTINUED: Air on the Move

When sunlight warms the land, and then warms the air near it, the molecules spread out a bit, taking up more space, just like the air at high altitude. The warmed air has lower pressure than the air around it, so it rises in the atmosphere, like the warmed balloon in the previous activity.

As the warmed air rises in the atmosphere, it cools down, because air at higher altitudes is cooler. Remember that cool air doesn't hold as much water vapor as warm air, so as warm air cools, some of the water vapor condenses into the tiny water droplets that make up clouds.

As air gets cooler, the molecules come closer together. The air has higher pressure than the air around it, so it sinks in the atmosphere, like the cooled balloon in the previous activity. Then, it can be warmed and rise again.

This cycle of rising and falling air is called **convection**.



EXPLAIN: Why does warm air go up and cool air go down?



How does air move and change when a storm is forming?

STEP 3: Create a model to describe how precipitation happens in an isolated storm.

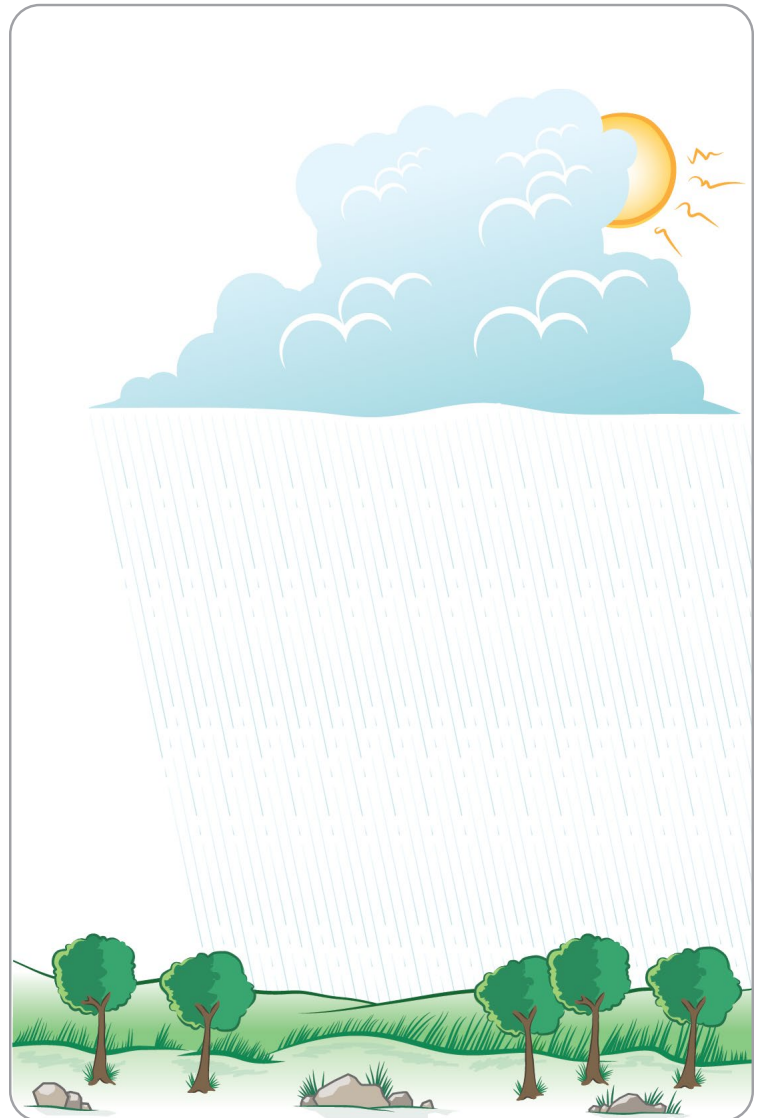
To get started, **draw and write** in the illustration to explain how precipitation happens in an isolated storm.

Make sure your model explains:

- What happens to energy from the Sun that leads to an isolated storm?
- What happens to water at the surface and clouds that lead to the isolated storm?
- How does air temperature and humidity change as air moves from the ground to the cloud?
- How does air move between the ground and where the storm forms?

Write an explanation that goes with your model and answer the question below:

EXPLAIN: What has to happen for an isolated storm to form?



LESSON
6

Can we identify the best conditions for storms?

STEP 1: Make predictions.

Use your model for an isolated storm, and what you know about temperature and humidity, to predict the very best conditions that would lead to an isolated storm.

A strong storm would form if the temperature high in the atmosphere near the clouds was

much colder than much warmer than about the same as

the temperature near the ground because: _____

A strong storm would form if humidity was high moderate low

because: _____



Can we identify the best conditions for storms?

STEP 2: Record and explain your observations.

Now you can test your predictions with the Make a Thunderstorm simulation (scied.ucar.edu/make-thunderstorm). Follow your teacher's instructions for collecting data from the simulation. Record your observations of five trials in the table below. Then explain why a storm did or did not form.

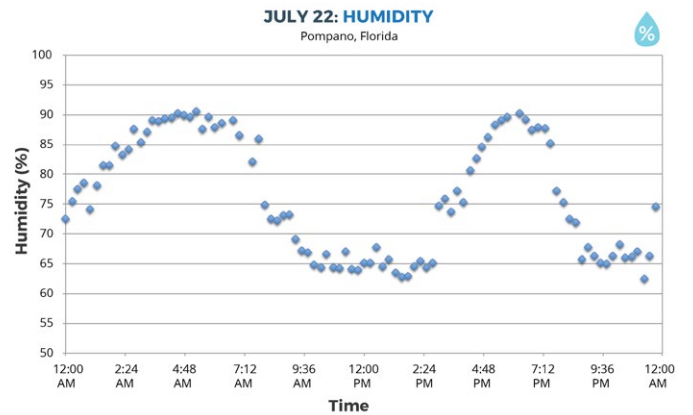
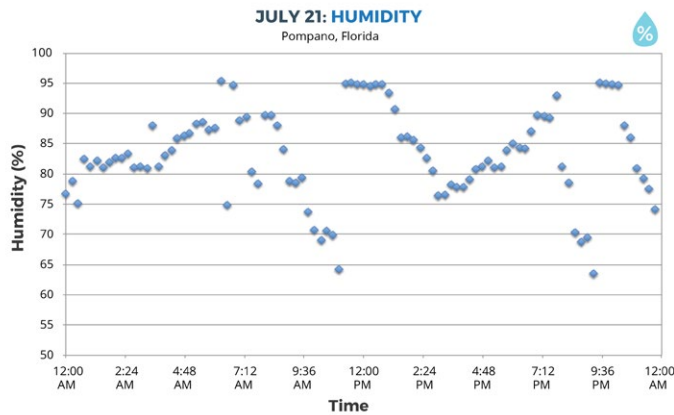
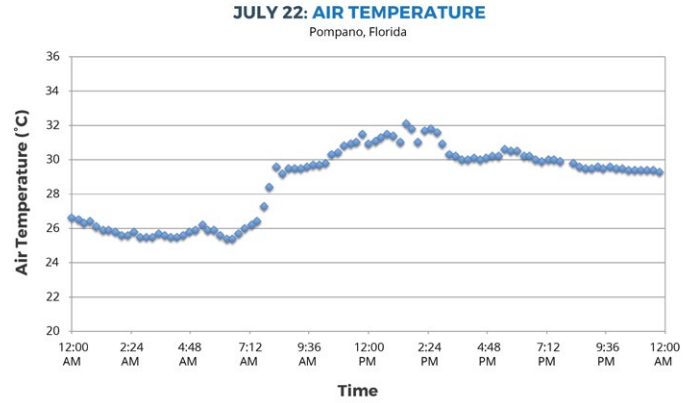
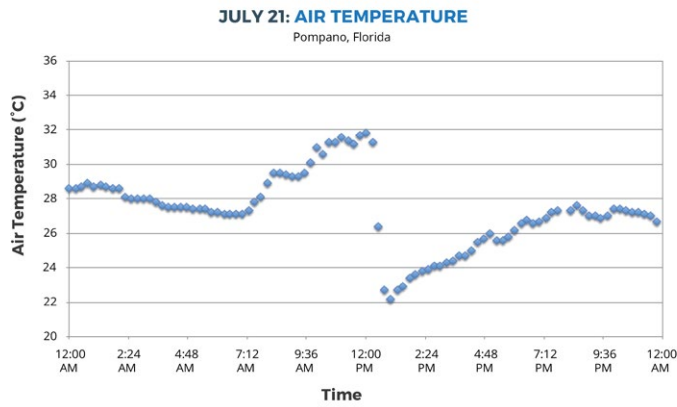
CONDITIONS	OUTCOME	WHY DID THIS HAPPEN? Explain what helped the storm or what was missing.
high-level temp <input type="text"/> humidity <input type="text"/> low-level temp <input type="text"/>	<input type="radio"/> no storm <input type="radio"/> small storm <input type="radio"/> medium storm <input type="radio"/> big storm	
high-level temp <input type="text"/> humidity <input type="text"/> low-level temp <input type="text"/>	<input type="radio"/> no storm <input type="radio"/> small storm <input type="radio"/> medium storm <input type="radio"/> big storm	
high-level temp <input type="text"/> humidity <input type="text"/> low-level temp <input type="text"/>	<input type="radio"/> no storm <input type="radio"/> small storm <input type="radio"/> medium storm <input type="radio"/> big storm	
high-level temp <input type="text"/> humidity <input type="text"/> low-level temp <input type="text"/>	<input type="radio"/> no storm <input type="radio"/> small storm <input type="radio"/> medium storm <input type="radio"/> big storm	
high-level temp <input type="text"/> humidity <input type="text"/> low-level temp <input type="text"/>	<input type="radio"/> no storm <input type="radio"/> small storm <input type="radio"/> medium storm <input type="radio"/> big storm	

Can we identify the best conditions for storms?

STEP 3: When did it rain?

The air temperature and humidity data below is from two days in Pompano, Florida. It rained on one of these days. Identify the most likely day and time it rained.

1. Circle on the graph when the rain happened.



2. Explain what conditions were likely leading up to this rain event, and why you think the rain happened at this time. Use evidence from previous investigations and your model to develop your explanation.



UCAR CENTER FOR
SCIENCE EDUCATION



LEARNING SEQUENCE 2

LESSON
7

What other types of storms cause precipitation?

LESSON
8

How is air changing before, during, and after a cold front?

LESSON
9

What causes precipitation along a cold front?

LESSON
10

What causes fronts to move?

LESSON
11

What could cause a front to stall?

LESSON 7

What other types of storms cause precipitation?



STEP 1: What do you notice about the cold front?

Watch the time-lapse video of a day when a cold front moved through Lyons, CO and observe how weather changes over time.

		SUNRISE TO NOON	NOON TO 4:00PM	4:00PM TO SUNSET
WIND	Wind speed:	<input type="radio"/> high <input type="radio"/> low	<input type="radio"/> high <input type="radio"/> low	<input type="radio"/> high <input type="radio"/> low
	Wind direction: <i>does it change?</i>			
CLOUDS	Cloud type: <i>what types are visible?</i>			
	Amount: <i>how much sky is covered with clouds?</i>			
PRECIPITATION	<i>When did precipitation happen?</i>			
	<i>Could you tell what kind: rain, snow, or other?</i>			
	<i>Was there a lot or a little?</i>			

1. How is the storm in the time-lapse video different from an isolated storm?

STEP 2: Brainstorm different kinds of storms.

Have you been in storms that are different from the isolated storms you investigated before?

Describe storms that you experienced, and explain what made them different from an isolated storm.

DESCRIBE THE STORM YOU EXPERIENCED.	HOW IS IT DIFFERENT FROM AN ISOLATED STORM?

What other types of storms cause precipitation?



STEP 3: Interpret a weather forecast for a cold front.

The seven-day forecast below shows a cold front moving through an area. Work with your group to interpret what is happening before, during, and after the front.

Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Mostly Sunny	Partly Cloudy	Partly Cloudy	Mostly Cloudy	Mostly Cloudy	Rain Showers	Sunny
Hi 68° Lo 55°	Hi 75° Lo 60°	Hi 74° Lo 60°	Hi 70° Lo 56°	Hi 70° Lo 55°	Hi 60° Lo 31°	Hi 47° Lo 30°

	BEFORE THE COLD FRONT (Sat. to Wed.)	DURING THE COLD FRONT (Thurs.)	AFTER THE COLD FRONT (Fri.)
TEMPERATURE	<p>The highest temperature was:</p> <p>The lowest temperature was:</p>		
HUMIDITY & CLOUDS	<p>We don't have humidity data, but we know clouds form with higher humidity. <i>When was humidity likely high or low?</i></p>		
PPTN	<p><i>When did precipitation happen? When did it not happen?</i></p>		

1. What do you think the air was like (temperature and humidity) in this location before the front?
2. What do you think the air was like (temperature and humidity) in this location after the front?
3. What do you think caused the precipitation during the front?

LESSON 8

How is air changing before, during, and after a cold front?

STEP 1: Describe the air temperature before, during, and after the cold front.

Imagine your town has just received a weather report that a cold front is heading your way. Read the weather report and analyze temperature, humidity, and wind data to figure out what happened during this storm.

WEATHER REPORT

A cold front is expected to change temperatures in the area after an extended warm-up. The cold front will arrive in South Riding, Virginia, on the morning of October 21, 2016. Be prepared for a change in temperature over two days as the front passes through the area, replacing a warm air mass with a cold air mass.

Circle the data on the graph that shows when the cold front passes through South Riding, VA. Describe the graph using the **What I See** and **What It Means** statements.

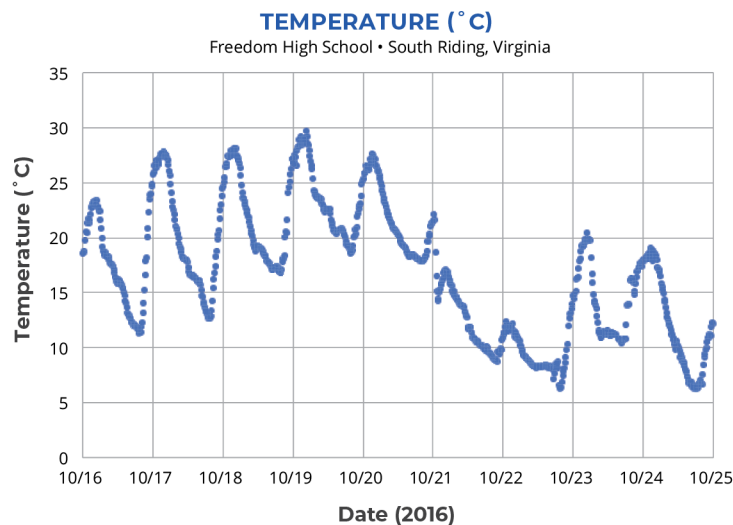


WHAT I SEE: Look at different parts of the graph. Do you notice patterns? Do you notice interesting differences? Write **What I See** statements on the graph to record your observations.



WHAT IT MEANS: Next to each **What I See** statement, write a **What It Means** statement to explain what you think is happening in each part of the graph.

Note: The vertical lines on the graph indicate noon on each of the dates listed on the x-axis.



1. Describe the air temperature pattern before the cold front.



How is air changing before, during, and after a cold front?

STEP 1 CONTINUED: Describe the air temperature before, during, and after the cold front.

- Describe the air temperature pattern after the cold front.
- How does air temperature change when the front moves through?

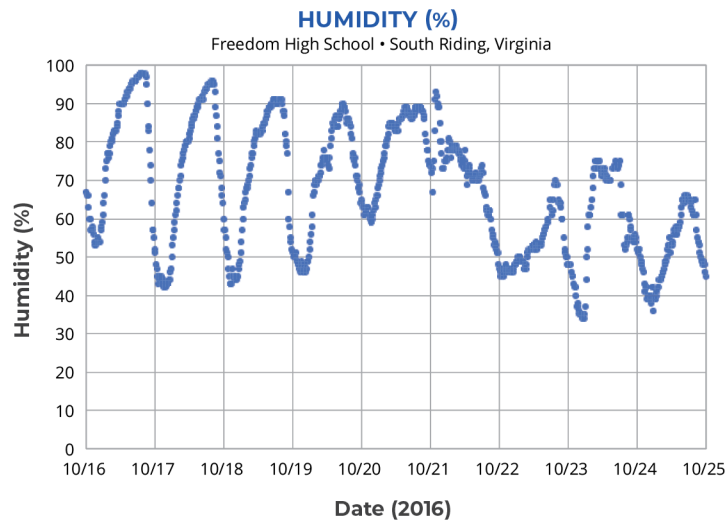


STEP 2: Describe the humidity before, during, and after the cold front.



Circle the data on the graph that shows when the cold front passes through South Riding, VA. Write **What I See** and **What it Means** statements on the graph.

Note: The vertical lines on the graph indicate noon on each of the dates listed on the x-axis.



- Describe the humidity pattern before the cold front.
- Describe the humidity pattern after the cold front.
- How does humidity change when the front moves through?



How is air changing before, during, and after a cold front?

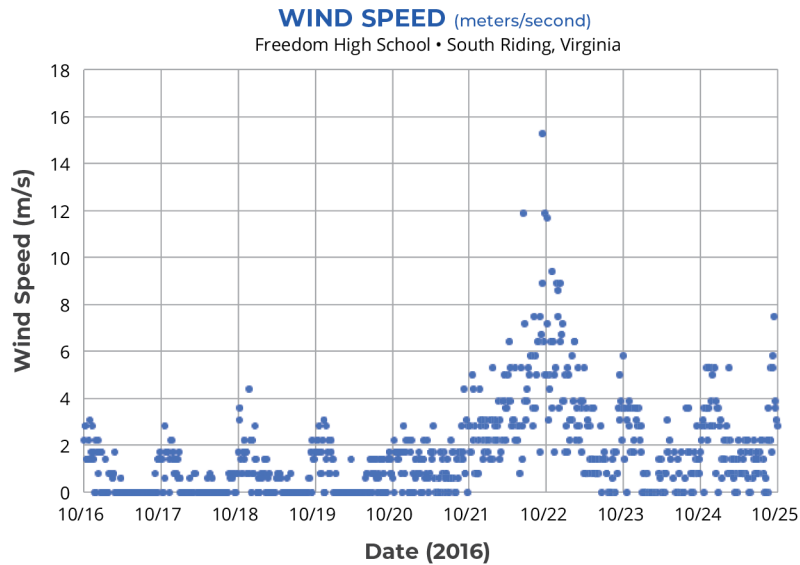


STEP 3: Describe the wind speed before, during, and after the cold front.



Circle the data on the graph that shows when the cold front passes through South Riding, VA. Write **What I See** and **What it Means** statements on the graph.

Note: The vertical lines on the graph indicate noon on each of the dates listed on the x-axis.



1. Describe the wind speed before the cold front.
2. Describe the wind speed after the cold front.
3. How does wind speed change as the front moves through?

WEATHER REPORT



...bring your umbrellas for the morning of October 21. The chance of rain is high.



DISCUSS WITH YOUR CLASS:

Why do you think the chances are high for precipitation the morning of October 21?

How is this storm similar to, or different from, the isolated storm that you investigated before?

Students at a high school in Virginia collected the weather data that's in this lesson's graphs.

If you collected weather data at your school, what types of weather events would you likely observe?




 LESSON
9

What causes precipitation along a cold front?

STEP 1: How does the air change as a front moves through a place?

Illustrate the weather conditions (temperature, humidity, and wind) you might see a day before the front, during the front, and a day after the front arrived at Freedom High School, South Riding, Virginia. Use color and symbols to show changes in temperature, humidity, and wind.

BEFORE	DURING	AFTER

CREATE A KEY:



Warm air



Cool air

(choose a color)



(choose symbols to show changes in humidity and wind)



STEP 2: Make observations of what happens to the warm and cool fluids in the tank.

Record your observations of the water tank in the space below. The tank is a model that uses warm and cool water to simulate warm and cool air in the atmosphere. With it, we can see what happens when warm air and cool air meet.

Make a cross section that shows what the tank looks like **BEFORE** the partition is removed.

Make a cross section that shows what the tank looks like right **AFTER** the partition is removed.



DISCUSS AS A CLASS:

What happened when the cold and warm fluids met?

What causes precipitation along a cold front?

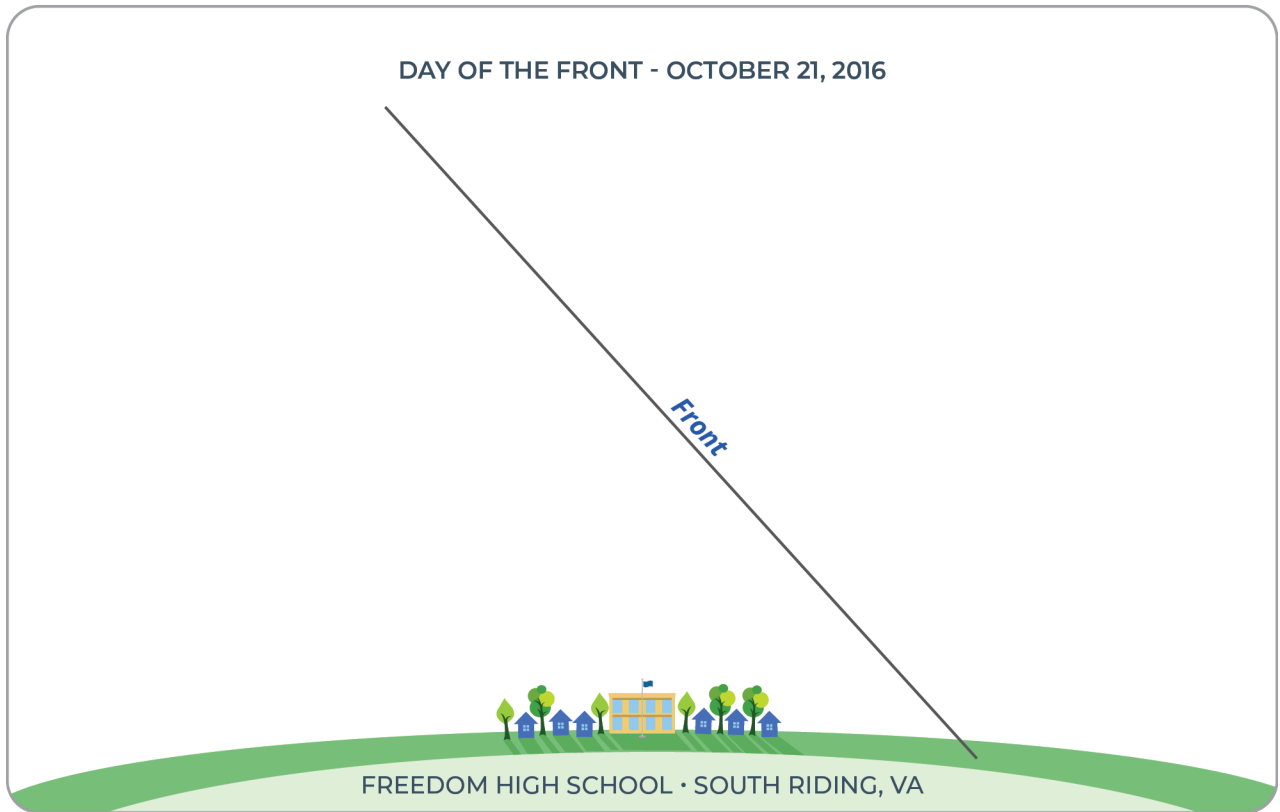


STEP 3: Develop a model for explaining precipitation during the cold front.

This model is a cross section of the atmosphere, just like the water tank that showed a cold front.

Draw on the model to explain:

1. The location of the cold air mass.
2. The location of the warm air mass.
3. The direction that each air mass is moving.
4. Where you'd expect clouds to form.



EXPLANATION: Write a caption for your model to explain why Freedom High School had precipitation on October 21, 2016.

What causes precipitation along a cold front?



STEP 4: Investigate air masses and fronts.

Over large areas, air can have similar temperature and moisture. Air with similar characteristics is called an air mass. For example, air over northern North America can form a cold, dry air mass. It is cold because it forms at high latitude, near the Arctic. It is dry because it forms over land, and there is little moisture evaporating from the land as compared with the ocean. Air over the Gulf of Mexico and the southern United States can form a warm, moist air mass. It is warm because it forms at a lower latitude, closer to the equator. Water evaporating from the Gulf of Mexico makes the air mass moist. The two kinds of air masses often “bump” into each other as they move, forming fronts.



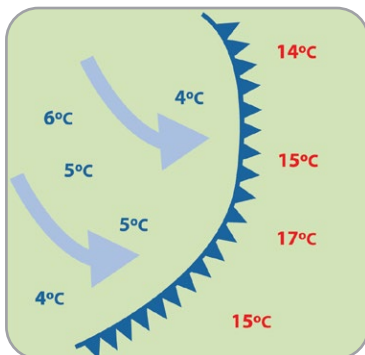
STOP AND THINK

What type of air mass was over Freedom High School before the front moved through the area?

What type of air mass was over Freedom High School after the front moved through the area?

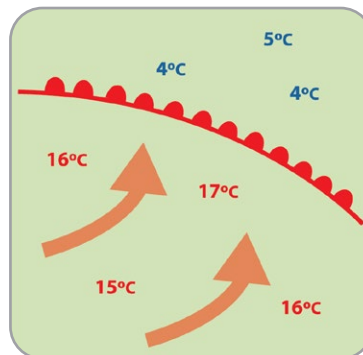
There are several different types of fronts. The type of front depends on how the air masses interact. The pictures below show how different types of fronts are shown on weather maps using symbols.

COLD FRONT



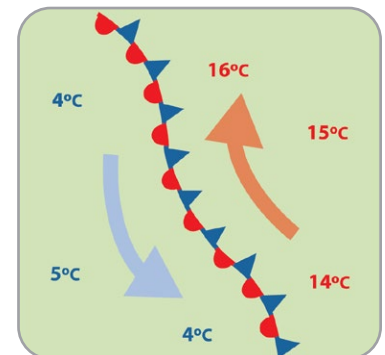
At a cold front, a colder air mass moves into a warmer air mass. A cold front is shown on a weather map as a blue line with triangles in the direction of movement.

WARM FRONT



At a warm front, a warmer air mass moves into a colder air mass. A warm front is shown on a weather map as a red line and half circles in the direction of movement.

STATIONARY FRONT



At a stationary front, a cold air mass and warm air mass are side by side. Both might be moving, but neither has enough force to move into the other's space. A stationary front is shown on a weather map with both red half circles and blue triangles.



LESSON 9

What causes precipitation along a cold front?

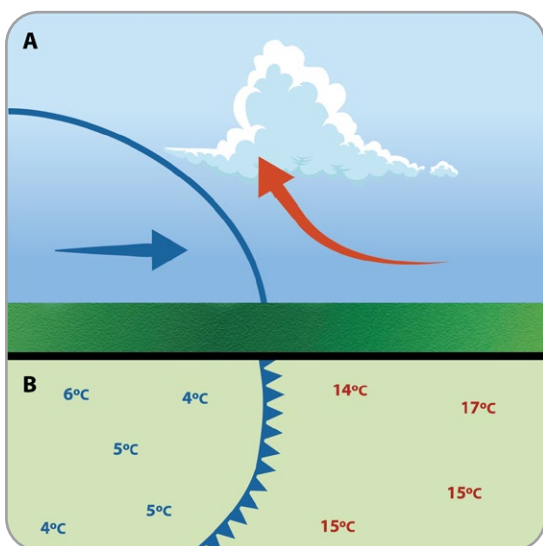
In this investigation, we are focusing on cold fronts.

Cold fronts can produce dramatic storms. Winds become gusty, and there is a sudden drop in temperature. There can be heavy rain, hail, thunder, and lightning. As warm air is pushed up at a cold front, cumulus clouds form just as they did in the isolated storms you learned about before – as the air moves upward it cools, and water vapor becomes liquid water droplets that make up clouds. The clouds may grow into cumulonimbus clouds and cause rain, or snow if the temperature is below freezing. After a cold front moves through, you may notice that the temperature cools down, the rain stops, and clear skies or other types of clouds replace the cumulus clouds.



STOP AND THINK

What happened as the cold air mass moved into the warm air mass at Freedom High School?



A: The upper part of this image shows a cross section of a cold front. This is where a cold air mass is pushing into a warm air mass. The warm air is pushed upward where it cools, and water vapor condenses into clouds.

B: The lower part of this image shows a weather map view of a cold front. The cold air mass is on the left side, pushing into a warm air mass. The blue line with triangles along it indicates the location where cool and warm air meet.

A cold front (and the cold air mass that moves in) may not be cold. During the summer, temperatures might be quite warm, but we can still have cold fronts. A cold front in the summer typically brings cooler weather compared with the previous days.

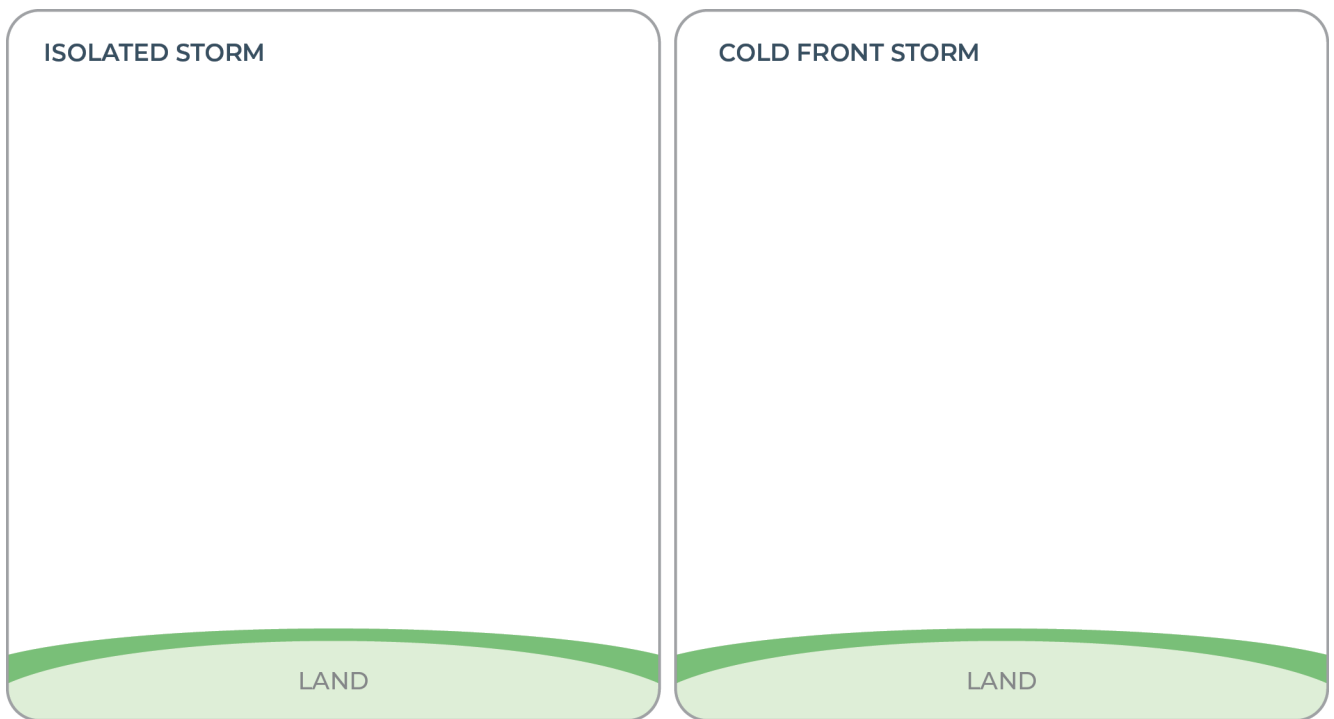
What causes precipitation along a cold front?



STEP 5: Let's compare our two types of storms: isolated storms and storms that form along a cold front.

Draw cross section models to explain how precipitation could happen in each kind of storm.

- Use the other models you've made and the reading in this lesson to help you decide what to draw.
- Indicate where air is warmer and where it is cooler.
- Use arrows to show how air moves.
- Show where clouds form in both types of storms.



1. How are isolated storms and cold front storms similar?

2. How are they different?

What causes precipitation along a cold front?

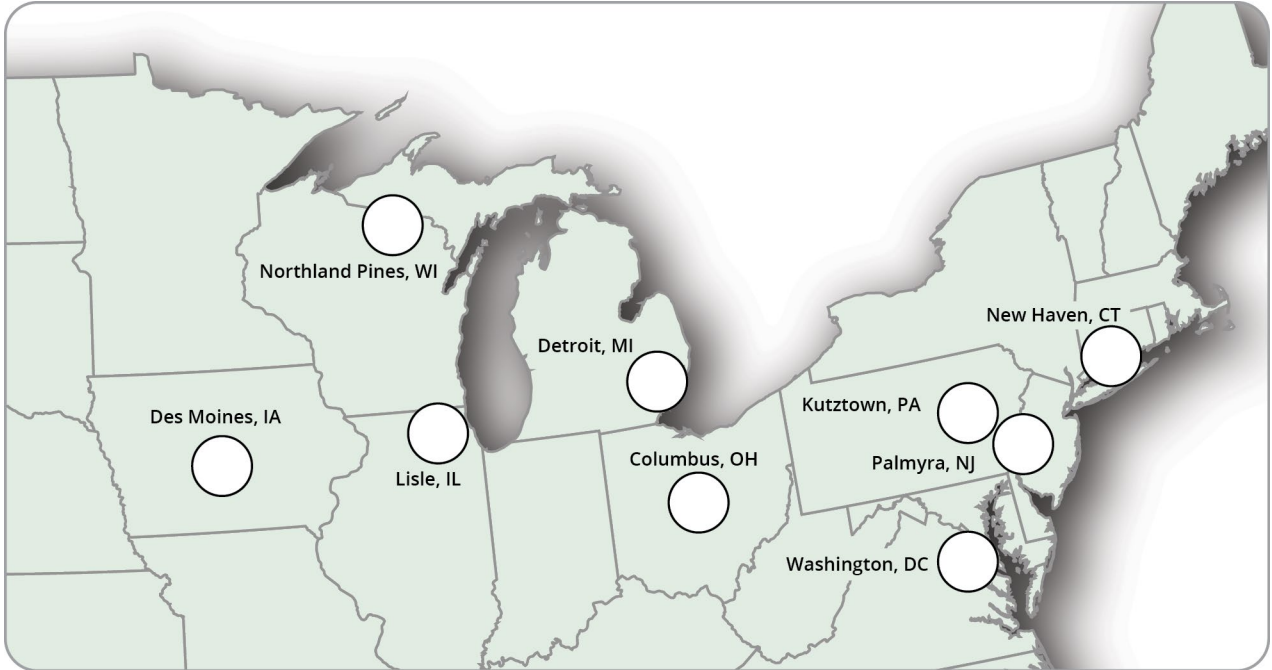


STEP 6: Focus on the big picture using our cold front model.




Your teacher will assign you to a group. Each member of your group will map weather data for one day over a four-day time period on the map on the following page. Then you'll look at all four maps together to see what happened as a cold front moved through this area, the Midwest, and Northeast.

- 1. Choose a day.** Each member in your group will choose one day of data to map. On the next page, circle your day on the Maximum Temperature and Precipitation Tables and write the date on your map.
- 2. Color and label your map.**
 - a. Color locations where the temperature is greater than 30°C RED.
 - b. Color locations where the temperature is equal to, or less than, 30°C BLUE.
 - c. Draw slanted rain lines near the location if it had precipitation.
 - d. Add the red and blue colors to the key.
- 3. Compare maps.** When your group completes all four maps, line them up in order beginning September 8 and ending with September 11.
- 4. Determine where the cold front is located.** Draw the front on each map using the blue line/blue triangle symbol.
- 5. Determine where the cold air mass is located.** Shade the cold air mass BLUE on each map.
- 6. Determine where the warm air mass is located.** Shade the warm air mass RED on each map.
- 7. Make observations of how the front and air masses move over time.** Be prepared to discuss your ideas.

What causes precipitation along a cold front?



DATE:

-  Max temperature above 30°C
-  Max temperature equal to or less than 30°C
-  Precipitation

MAXIMUM TEMPERATURE (°C)

	9/8/15	9/9/15	9/10/15	9/11/15
Des Moines, IA	27.8	27.8	28.9	21.1
Northland Pines, WI	25.4	22.7	19.6	16.9
Lisle, IL	31.7	23.3	25.6	19.6
Detroit, MI	31.2	30.1	24.7	25.8
Columbus, OH	32.7	30.9	26.1	28.2
Washington, DC	33.3	34.4	28.9	30.5
Palmyra, NJ	32.2	32.7	33.9	26
Kutztown, PA	31.2	32.5	32.7	22
New Haven, CT	32.8	30	25	26.7

PRECIPITATION (CM)

	9/8/15	9/9/15	9/10/15	9/11/15
Des Moines, IA	0.3	0	0	0
Northland Pines, WI	0.5	0.1	0	0.1
Lisle, IL	2.2	0	0.9	1.5
Detroit, MI	0	0.1	0	0.6
Columbus, OH	0	0	0	1.6
Washington, DC	0	0	0.3	0
Palmyra, NJ	0	0	3.6	0.1
Kutztown, PA	0	0.6	3.6	0
New Haven, CT	0	0	0	0

LESSON
10

What causes fronts to move?

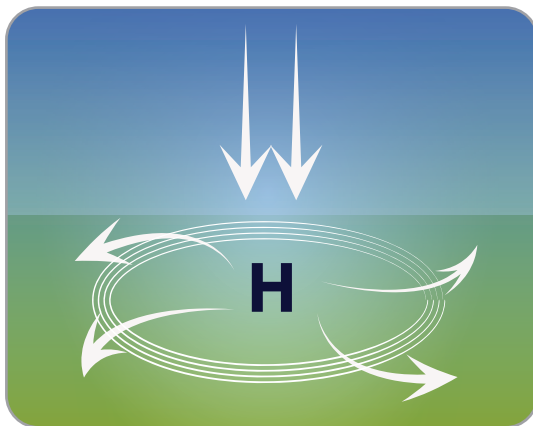
STEP 1: Remember air pressure? There's more to it.

In Lesson 5 you learned that air pressure causes air to move.

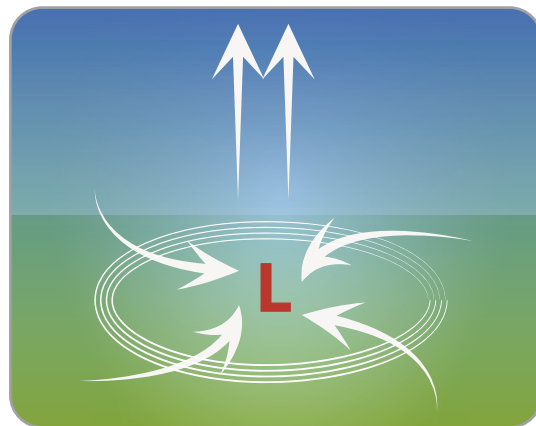
- Air rises in the atmosphere when it has lower pressure.
- Air sinks in the atmosphere when it has higher pressure.

You learned how air moving up and down is able to cause a small isolated storm. It turns out the same thing can happen over vast areas (the size of large US states), and this creates winds that can move fronts.

Air pressure isn't always the same from place to place. In one location, air might have somewhat lower pressure, which causes it to move upward. In another location, air might have somewhat higher pressure, which causes it to move downward.



In areas with high pressure, air moves downward and spreads outward once it gets to the land. High pressure is marked with a blue H on weather maps.



In areas with low pressure, air moves upward, so nearby air rushes in to fill the space. Low pressure is marked with a red L on weather maps.

The air rushing into low pressure and away from high pressure is wind.

Measurements of air pressure are made using an instrument called a barometer. Barometers used for weather measurements record the pressure in units called millibars (mb). The average air pressure at ground level is 1013.3 mb.



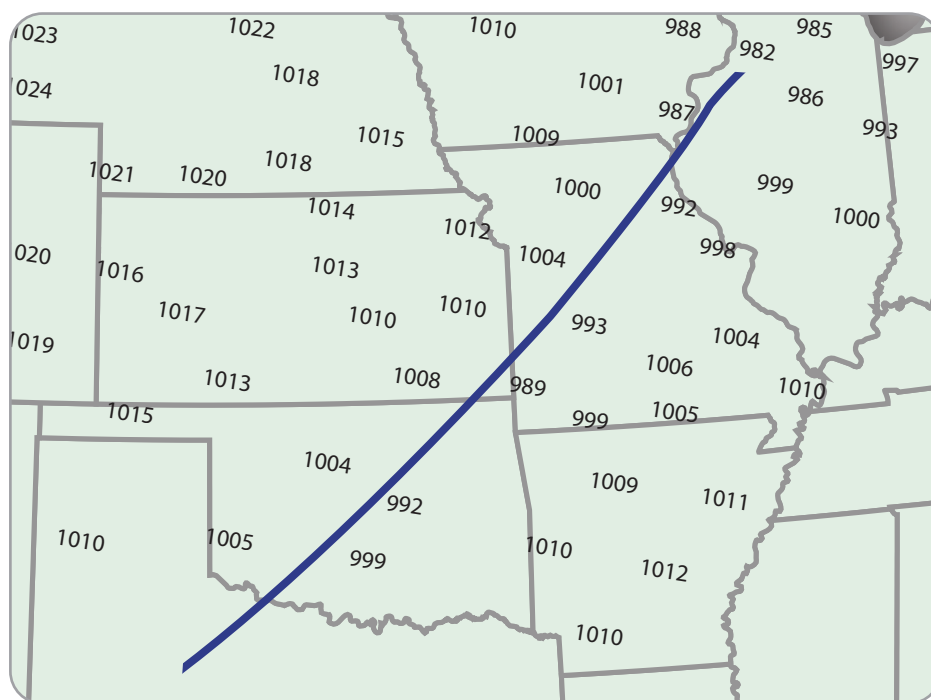
What causes fronts to move?

STEP 2: Analyze pressure data over a region.

Follow the instructions to identify and analyze areas of high pressure and low pressure on the map below and figure out which direction the cold front is moving.

- Color code the areas with high and low pressures (and add the colors to the key).
 - Highlight the highest pressures on the map (more than 1015 mb) with a colored pencil.
 - Highlight the lowest pressures (less than 995 mb) with a different colored pencil.
- Draw arrows on the map to indicate the direction that the wind is blowing. Remember that wind flows away from high pressure and towards low pressure.
- Based on the direction that wind is blowing, draw triangles on the front. (The triangles should point in the direction that the front is moving.)
- The areas with the highest pressure and lowest pressure are labeled on a weather map (like the symbols in the key).
 - Mark the location with the highest pressure on the map with a blue H.
 - Mark the location with the lowest pressure on the map with a red L.

PRESSURE MEASURED IN MILLIBARS (mb)



KEY:

L the center of an area of low pressure
H the center of an area of high pressure

cold front

1014.4 1014.6
1015.8
barometric pressure (mb)

highest pressures - more than 1015 mb (choose a color)
 lowest pressures - less than 995 mb (choose a color)



DISCUSS AS A CLASS:

Which way did the wind blow? What evidence do you have to support your claim?



What causes fronts to move?

STEP 3: Analyze pressure data in one location.

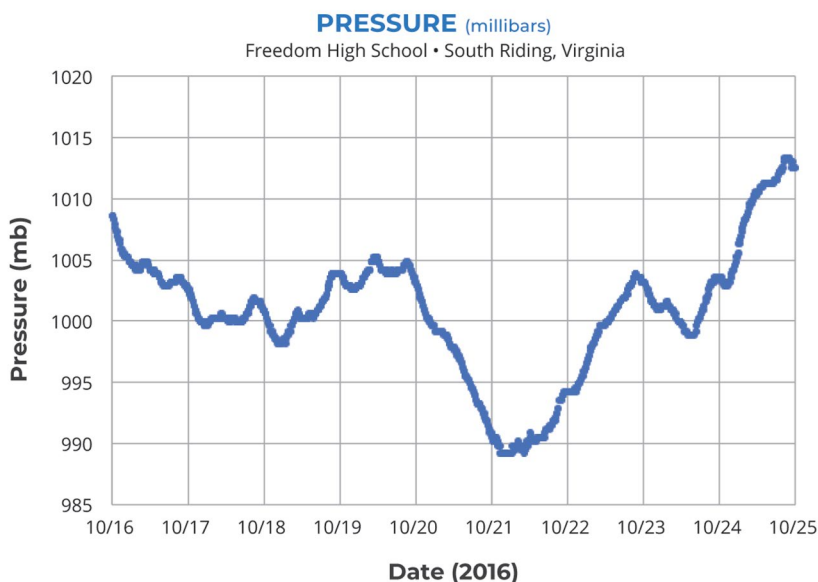
In Lesson 8 you looked at weather data from Freedom High School in South Riding, Virginia, over a 10-day period, when a cold front passed through the area. The pressure data below was collected at Freedom High School during that same 10-day period. Remember that the cold front arrived at Freedom High School early on October 21.



How did the pressure change over time? Add **What I See** and **What It Means** statements to describe the pressure before, during, and after the cold front.



Note: The vertical lines on the graph indicate noon on each of the dates listed on the x-axis.



1. When was barometric pressure the lowest? When was it the highest?
2. Write a sentence to describe where pressure is lowest and highest around a cold front.
3. Take a look at the wind data in Lesson 8. The windiest time during this storm was when the pressure was lowest. Write a sentence to explain why winds happen when air pressure is low.



LESSON
11

What could cause a front to stall?

Even though Colorado is far from the ocean and other large bodies of water, there was an unusually high amount of moisture in the air above Colorado, and the storm didn't move for days, which led to the flooding event in September 2013. In this activity, you'll examine information about the storm. Your goal is to figure out what led to so much moisture in the atmosphere and to develop a model to show why this precipitation event lasted so long over Colorado.

STEP 1: Analyze data for the Colorado storm.

Using the table of daily rainfall totals collected during the storm at Centennial Middle School in Boulder, Colorado, choose which of the claims below you believe is true about the Colorado storm in September 2013.

DATE	RAINFALL* (mm)
9/10/2013	23.9
9/11/2013	35.1
9/12/2013	214.1
9/13/2013	84.1
9/14/2013	0.8
9/15/2013	4.8
9/16/2013	36.8

**Rainfall totals are for the same Colorado storm, which lasted for seven days.*

- The Colorado Storm in September 2013 was an isolated storm.
 - The Colorado Storm in September 2013 was a cold front.
 - The Colorado Storm in September 2013 was unlike either an isolated storm or a cold front.
- 1.** Explain why the claim you chose is true. Use evidence to support your claim.

What could cause a front to stall?

STEP 2: Interpret the storm report.

Read the storm report below to collect information about how the air was moving, how moisture was moving, and where rain was falling during the storm.

STORM REPORT

High Pressure: There was high pressure to the north, over Wyoming, which was pushing a cold air mass south and there was a high pressure area to the south, over Mexico, and high pressure to the east over Tennessee and the surrounding area. This caused the front to stall over Colorado.

Low Pressure and Moisture: Low pressure over Utah and Nevada pulled warm, humid air from the Gulf of Mexico and eastern Pacific into the storm.

The Effect of Mountains: As the air traveled up the eastern side of the Rocky Mountains, it formed clouds and then rain, and remained in place for days.

Create a model for the storm: Use the symbols from the key and the information in the storm report to develop a model. Indicate on the model the direction air is moving based on the highs and lows, and where the humid air that caused the storm is coming from.



KEY:

L
the center of an area of low pressure

H
the center of an area of high pressure



cold front

○ area of rain
(choose a color)

What could cause a front to stall?

STEP 3: Use your model to explain what happened in Colorado.

Use your model of the Colorado storm to answer the questions below.

1. Where did the moisture come from for the storm?
2. What kinds of air masses interacted in the storm? Which air mass had the moisture for the storm?
3. What caused the precipitation at the front?
4. Why did the front stall, causing days of drenching rain in parts of Colorado?



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LEARNING SEQUENCE 3

LESSON 12

HOW DO STORMS MOVE AROUND THE WORLD?

LESSON 13

WHY IS IT HOTTER AT THE EQUATOR THAN OTHER PLACES ON EARTH?

LESSON 14

HOW AND WHY DOES AIR MOVE IN THE TROPICS?

LESSON 15

WHEN AIR AND STORMS MOVE, WHY DO THEY CURVE?

LESSON
12

How do storms move around the world?

**STEP 1: How do storms move across North America?**

Watch the video of storms moving across North America and draw arrows on the map below to record the patterns of storms you observe.

Draw arrows to indicate the direction that each storm moves through this region.

**STEP 2: Why is this pattern important?**

Explain below why it would be helpful to understand the patterns of storm movement.

How do storms move around the world?

**STEP 3: Observe precipitation movement around the world.**

Watch a video of storms as they move around the world. How do storms move near the equator? In the tropics? In the midlatitudes?

Draw arrows on and write on the map below to record your observations of moving storms from the video.

**STEP 4: Discuss your observations.**

Discuss the following questions with your peers and record your answers below. Be ready to share your ideas in a whole class discussion-

1. What patterns did you notice about how precipitation moves around the world?

2. What questions do you have about these patterns?

LESSON
13

Why is it hotter at the equator than other places on Earth?

**STEP 1: Observe patterns in average annual temperatures.**

Look closely at the World Average Temperatures slide.

1. Where are temperatures cooler?
2. Where are they warmer?
3. What patterns do you notice?

Draw and write your answers to the questions above on the map below.



Record your ideas about why it's hotter at the equator than other places on Earth.



Why is it hotter at the equator than other places on Earth?



STEP 2: Observe energy angles.

Work in groups of three to investigate what happens to light when it shines on graph paper at different angles. Be prepared to share your ideas.

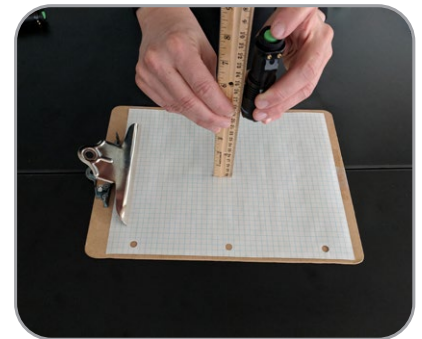
Materials: A clipboard or flat surface, flashlight, ruler, one sheet of graph paper, pencil

What does the flashlight represent in this investigation?

What does the clipboard represent in this investigation?

INSTRUCTIONS:

1. Decide who will hold the flashlight and ruler, who will hold the clipboard, and who will record.
2. Put a piece of graph paper on your clipboard and lay it flat on the table.
3. To investigate what happens to light that shines at different angles onto a surface, follow these steps:
 - a. Turn on the flashlight and hold it directly above the clipboard.
 - b. Adjust the distance between the flashlight and the clipboard so that the light shines entirely on the graph paper, with lots of space around the edges. Use your ruler to measure the distance.
Note: This distance will vary depending on how bright your flashlight is, but try about 4-5 cm and move closer or further away as needed.
 - c. The recorder will trace the edges of the light pattern onto the graph paper. Be sure that the flashlight is pointed straight down when you take this measurement!
 - d. Label this image "straight on."
 - e. Next, tip the clipboard so that the light shines on graph paper at an angle, as shown in the picture at the right. Remember to hold the flashlight the same distance from the clipboard as you did when taking the "straight on" measurement (Use your ruler!). Again, be sure that the flashlight is pointing straight down towards the table like it was when you made the "straight on" measurement.
 - f. The recorder should trace the new pattern of light on the graph paper.
 - g. Label the new image "tilted."
 - h. Now, tip the clipboard at different angles and observe what happens to the light. You do not need to record these images. Just notice what happens to the light when you have less of a slant (less of an angle) versus more of a slant (a greater angle).



STRAIGHT ON



TILTED



DISCUSS WITH YOUR GROUP:

- Describe how the pattern of light changes when the clipboard changes from flat to angled.
- Do you observe any difference in the brightness of the light?
- Think about the amount of light energy from the flashlight that reaches any particular square on the graph paper. How does this change when you change the angle of the clipboard?

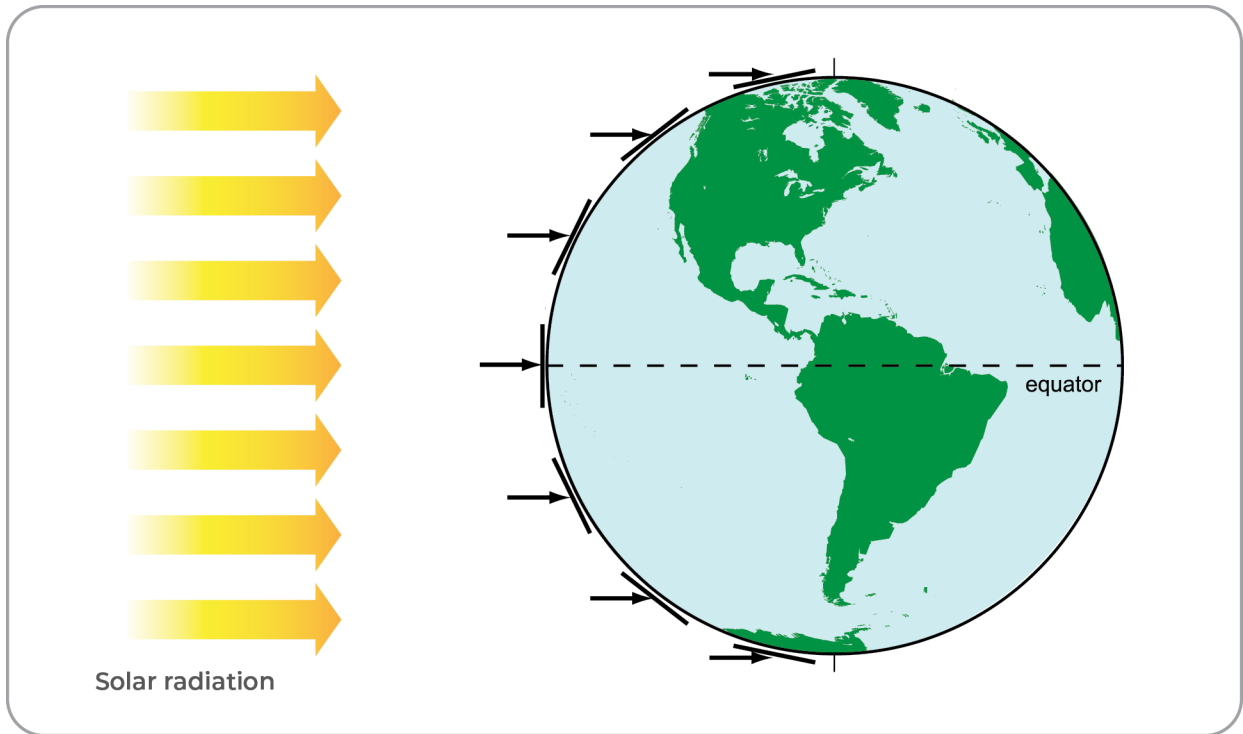


Why is it hotter at the equator than other places on Earth?

STEP 3: Think about the Sun's incoming energy.

Use the image below to think about where solar radiation (sunlight) is more direct and where it is more spread out on Earth's surface. Then answer the questions below.

THE SUN'S INCOMING ENERGY - ANGLE RELATED TO LATITUDE



1. Which area receives more concentrated sunlight? What is your evidence?
2. Which area receives less concentrated sunlight? What is your evidence?
3. How does the concentration of sunlight affect temperatures? Which areas are hotter? Which areas are colder?



Why is it hotter at the equator than other places on Earth?



STEP 4: Analyze temperature and latitude.

Your teacher will provide you with graphs of daily maximum temperature. Students at schools in Finland, Vermont (US), Arizona (US), Saudi Arabia, and Sri Lanka collected these data. Work with your group to match the graphs with the location where you think that data was collected. Use the clues below to help you decide how graphs and locations match:

CLUE 1: Seasonal differences are stronger at higher latitude (further from the equator). At or near the equator there is usually no seasonal difference in temperature.

CLUE 2: Temperatures are warmer at low latitude (close to the equator) than at high latitude (far from the equator).

	GRAPH (letter)	LOWEST MAXIMUM TEMPERATURE	HIGHEST MAXIMUM TEMPERATURE	DIFFERENCE IN TEMPERATURE (highest minus lowest)
Finland				
This is why I think Finland matches this graph:				
Vermont, US				
This is why I think Vermont matches this graph:				
Arizona, US				
This is why I think Arizona matches this graph:				
Saudi Arabia				
This is why I think Saudi Arabia matches this graph:				
Sri Lanka				
This is why I think Sri Lanka matches this graph:				

LESSON 14

How and why does air move in the tropics?

STEP 1: Develop a model.

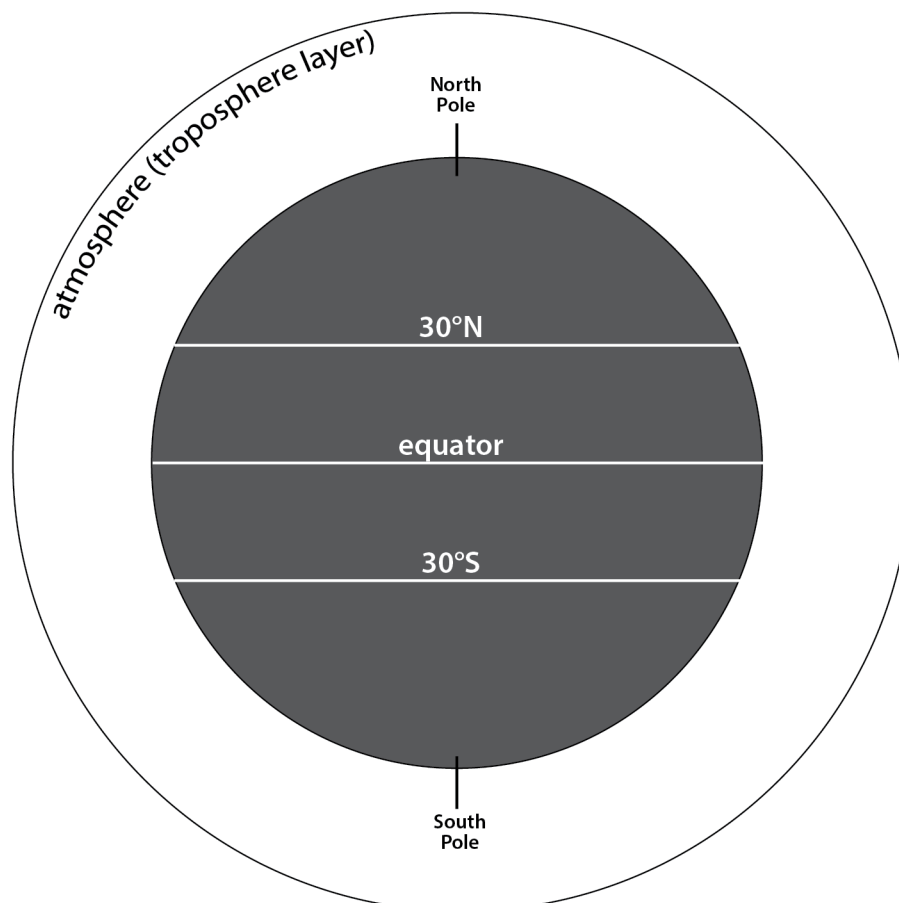
How do you think air is moving in the tropics between 30°N and 30°S? Why? Record your initial ideas on the image below.

Temperature differences cause air to move around the world.

- In some places, warm temperatures cause air to rise from the Earth's surface to higher in the atmosphere.
- In other places, cooler temperatures cause air to sink from higher in the atmosphere to the Earth's surface.

Translate those ideas to the illustration of Earth's atmosphere below. In the illustration, the atmosphere is exaggerated.

1. **Draw arrows in the troposphere layer of the atmosphere** to indicate where air is rising. Remember that warm air rises.
2. Air can't rise forever. **Draw arrows** to indicate where you think the rising air goes when it gets to the top of the troposphere.
3. At 30°N and 30°S latitude, air is cooler than it is at the equator. **Draw arrows** in the atmosphere to indicate what happens to the cooler air.



How and why does air move in the tropics?



STEP 2: Investigate air movement across Earth’s surface.

With a partner, write a statement that connects the water tank demonstration to the real world and explains why they are alike. The first part of the model is completed for you as an example.

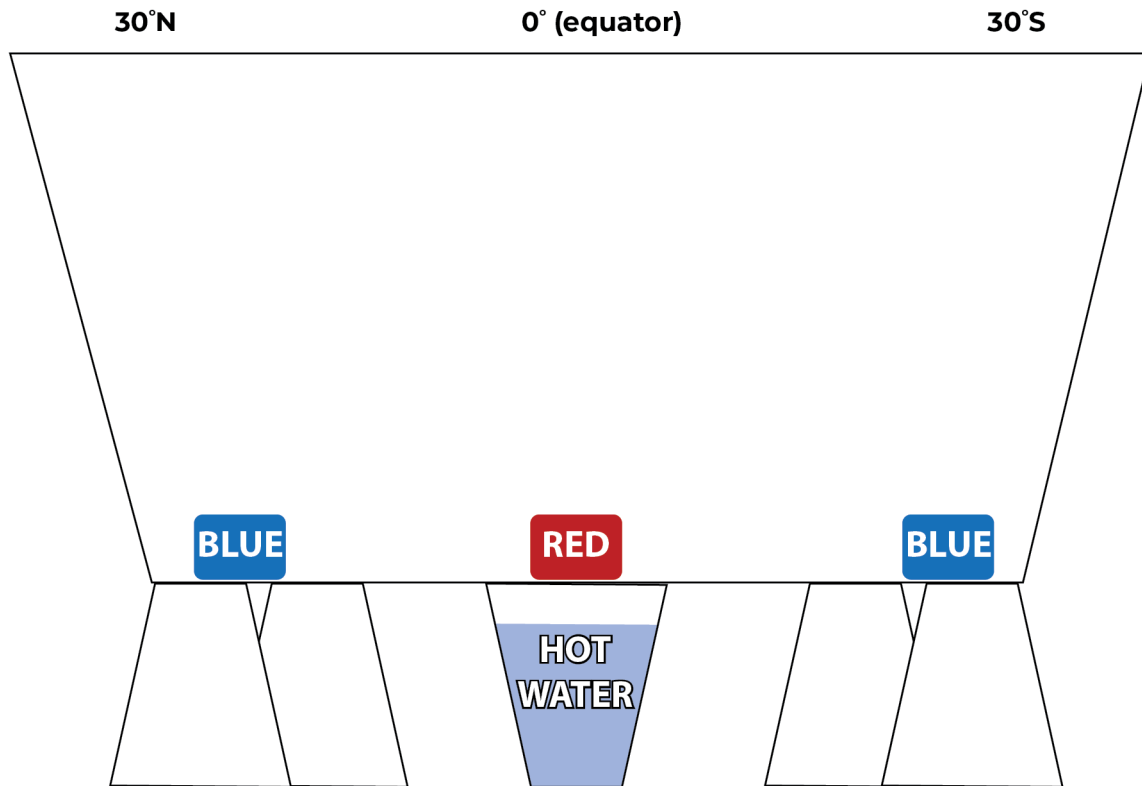
PART OF THE MODEL		PART OF THE REAL WORLD		WHY ARE THEY ALIKE?
The water in the tank	<i>is like</i>	<i>the Earth's atmosphere</i>	<i>because</i>	<i>the water in the clear plastic tub represents the air surrounding the Earth. Air and water are both fluids, so they behave similarly.</i>
Red food coloring	<i>is like</i>		<i>because</i>	
Blue food coloring	<i>is like</i>		<i>because</i>	
The cup of boiling hot water:	<i>is like</i>		<i>because</i>	
The bottom of the clear plastic water tub	<i>is like</i>		<i>because</i>	

How and why does air move in the tropics?



STEP 3: Record observations of the water movement.

Draw how the water moves through the tank.



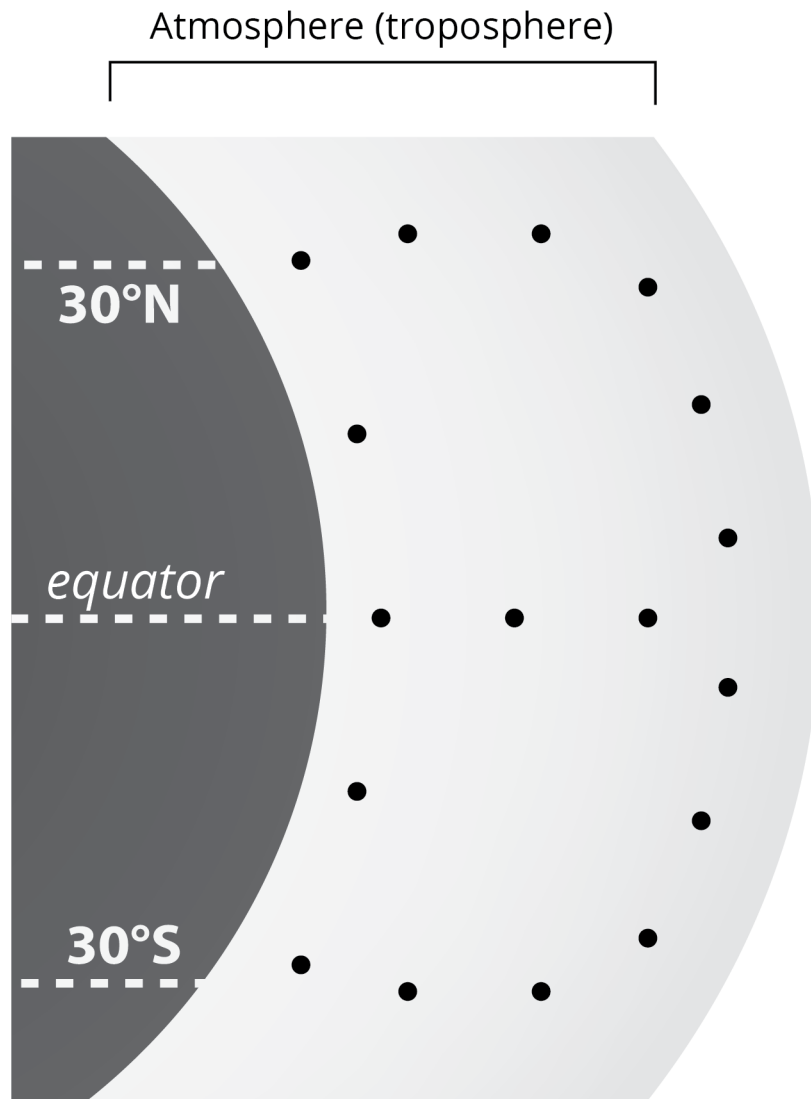
RECORD YOUR OBSERVATIONS <i>I notice...</i>	RECORD IDEAS FOR WHY <i>I think...</i>	RECORD YOUR QUESTIONS <i>I wonder...</i>

How and why does air move in the tropics?



STEP 4: Describe how and why air moves in the tropics.

Focus on how air is moving in the tropics (between 30°N and 30°S of the equator). Draw arrows to connect the dots and show how air is moving in the atmosphere, just as the water moved in the water tank model.



Write a caption to describe air movement in the model above.

How and why does air move in the tropics?




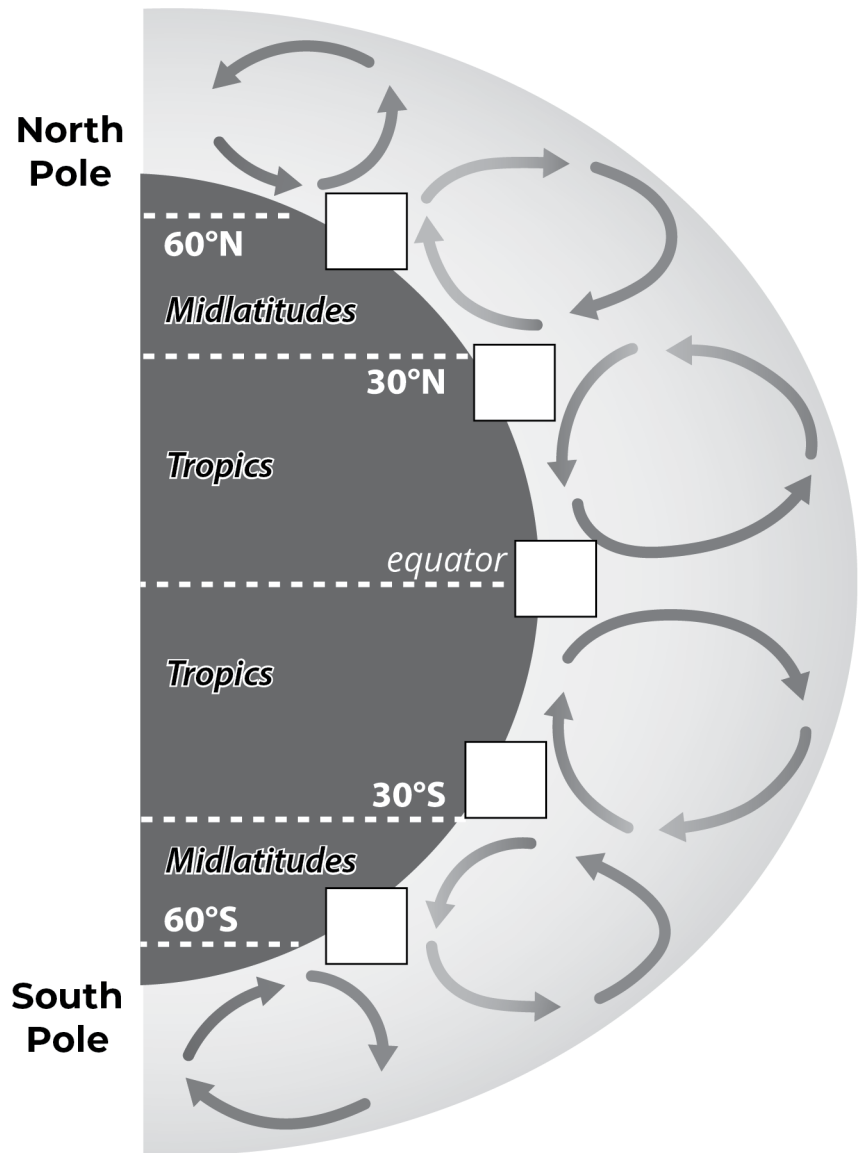
STEP 5: Create a model to describe air pressure and clouds at different latitudes.

Review the following diagram of how air moves around the world.

L Put an "L" in the white boxes where there would be low pressure.

H Put an "H" in the white boxes where there would be high pressure.

 Draw in clouds at locations of low pressure, where they are likely to form.



LESSON
15

When air and storms move, why do they curve?

STEP 1: Compare storm movement with your model.

Watch the *Global Rainfall and Snowfall* video from Lesson 12 again, this time focusing your observations on the movement of storms in the tropics. Below, compare the movement you see in the video to how you might predict storms to move based on your model about air movement in the tropics (from the end of Lesson 14).

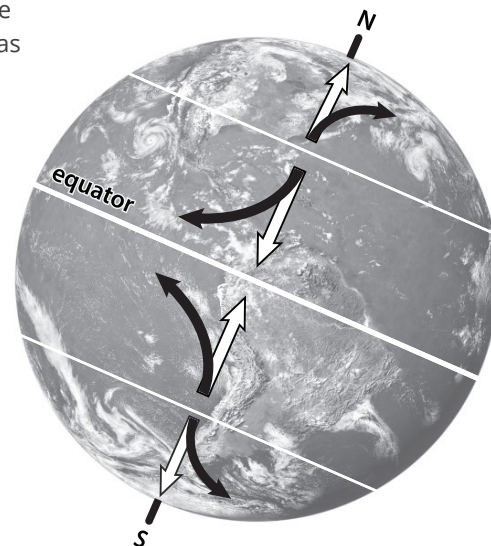
1. What kind of movement did you observe in the video that isn't explained by your model?



When air and storms move, why do they curve?

STEP 2: Learn about the Coriolis effect.

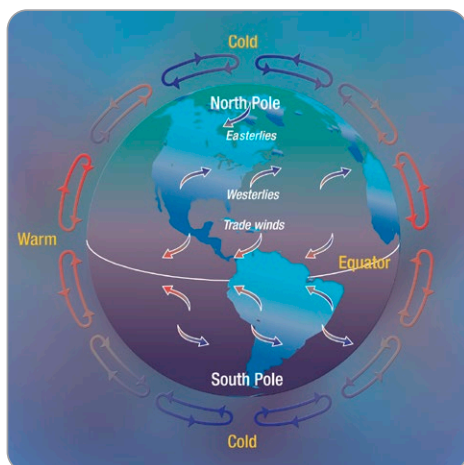
Because Earth is spinning, air does not travel in a straight line above the surface (like the white arrows on the picture to the right). Instead, air has a curved path (like the black arrows). Air north of the equator turns to the right as it moves. Air south of the equator turns to the left as it moves. This is called the **Coriolis effect**.



STOP AND DO

Make a model of the Coriolis effect.

- Make a model of the Earth.
 - Inflate** the balloon.
 - Draw** an equator around the widest point.
 - Draw** lines around the balloon where 30° N latitude and 30° S latitude lines would be.
- Simulate how air in the tropics would move if the Earth didn't spin.
 - Student 1:* **hold the balloon** in front of you so that the equator and latitude lines are parallel to the floor.
 - Student 2:* **draw an arrow** starting at 30° N latitude going toward the equator.
- Simulate how air moves with Earth's spin.
 - Student 1:* **slowly rotate** the balloon counterclockwise to model the Earth spinning on its axis. (Look at the balloon from above to determine which direction is counterclockwise.)
 - Student 2:* **draw another arrow**, starting from the same point as before and trying to get to the equator.



Why does air move in different directions in the tropics and in the midlatitudes?

Earth is always on the move. Earth rotates, or spins, making one full turn every 24 hours. If Earth did not spin, air would rise at the equator and sink at the poles. But because Earth spins, there are three areas of convection north of the equator and three south of the equator. Convection causes winds to move across Earth's surface toward the equator in the tropics, away from the equator in the mid-latitudes, and toward the equator around each pole. These winds are called **prevailing winds**. Prevailing winds curve because of the Coriolis effect. Winds in the midlatitudes curve, moving west to east. Winds in the tropics generally move from east to west.





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CULMINATING TASK

CULMINATING TASK: Challenge 1

CALIFORNIA STORM

CULMINATING TASK: Challenge 2

WHERE'S THE SNOW?

CULMINATING TASK: Challenge 3

WE'RE WARNING YOU

CULMINATING TASK: Challenge 1

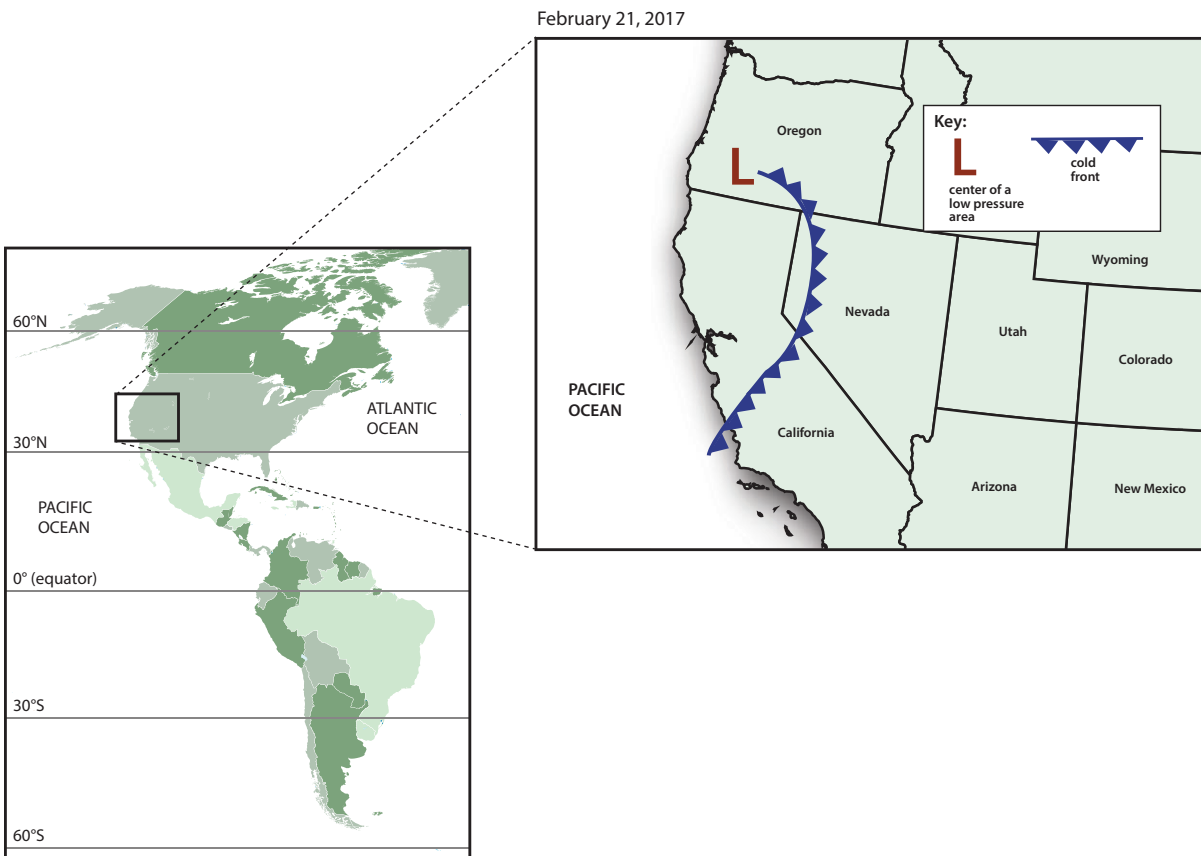
Why did the storm cause rain in some places and snow in other places in California?

On February 20, 2017, a storm passed through California on the West Coast of the United States. The storm brought extreme rainfall which caused flooding and mudslides in some places. The storm brought deep snow to mountainous areas of California.

USA TODAY:

Battered Northern California blasted by new storm

"The National Weather Service was calling for up to eight inches of rain over parts of the region Monday and Tuesday. Wind gusts in some areas could reach 65 mph. Flood warnings for a handful of rivers could last until week's end — this for a state that two months ago was mired in severe drought. Heavy snow was forecast to pound the Sierra Nevada Mountains, where totals will be measured in feet, not inches."



Why did the storm cause rain in some places and snow in other places in California?



STEP 1: Analyzing the California storm.

Use the maps on the previous page and what you have learned about storms to answer the questions below.

1. Based on what you learned about global winds, where do you think the cold front was located before it passed over California?
2. For a storm to cause rain and snow, there must be moisture in the air (humidity). Where do you think the moisture in this storm came from before it was in the atmosphere? Consider what you know about the water cycle as you answer.
3. Based on what you learned about cold fronts and the symbols on the weather map on the previous page, where do you think the storm will go next? How do you know?

Why did the storm cause rain in some places and snow in other places in California?

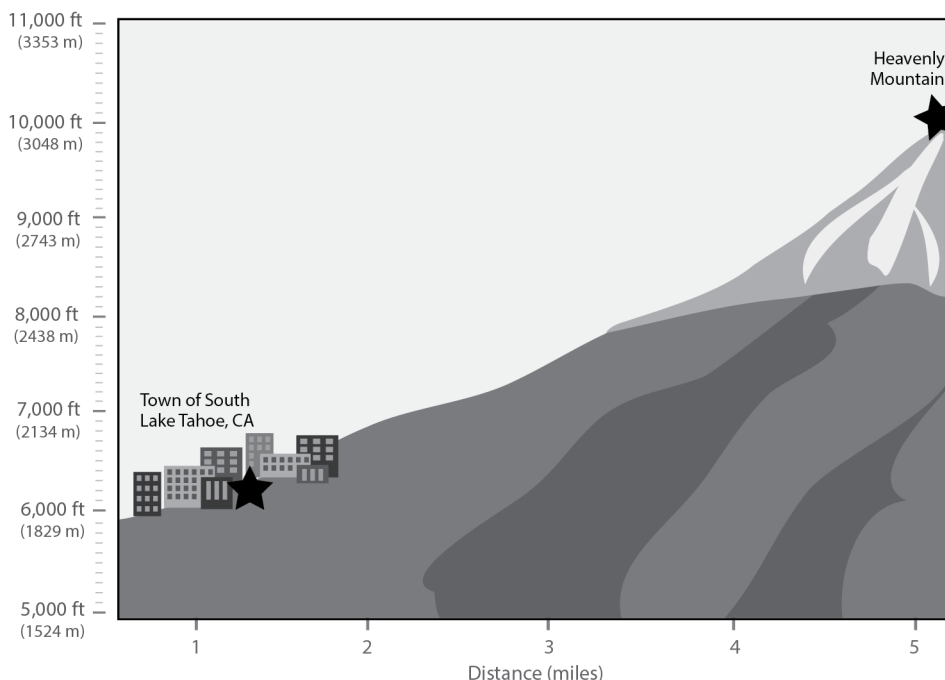


STEP 2: More details about the California storm: On February 21, 2017, the town of South Lake Tahoe, California, had 6.1 cm (2.4 inches) of rain. Meanwhile, the nearby summit of Heavenly Mountain had 61 cm (24 inches) of snow.

1. What information would you need to decide whether rain or snow will fall during a storm? Explain your answer.

2. Look below at the cross section showing the town of South Lake Tahoe and Heavenly Mountain. Use what you know about the atmosphere to explain why it snowed on Heavenly Mountain, but rained in the town of South Lake Tahoe.

3. Draw on the cross section below.
 - a. Indicate where the atmosphere is colder and where the atmosphere is warmer.
 - b. Indicate the location where it rained and the location where it snowed. Also indicate where along the ground you think a rain/snow mix may have fallen.
 - c. Indicate if there are places where you would like more information to know whether rain, snow, or a rain/snow mixture fell.



CULMINATING TASK: Challenge 2

As the storm moved east, why did it snow in some areas but not others?

Over a few days, the cold front and the low pressure center moved. From February 20 to 22, the storm moved gradually from California to Nevada. Then, on February 23, the storm moved more quickly to the east and south. In the middle of the country, temperatures were cold enough for snow.



As the storm moved east, why did it snow in some areas but not others?



STEP 1: Map the snowfall data.

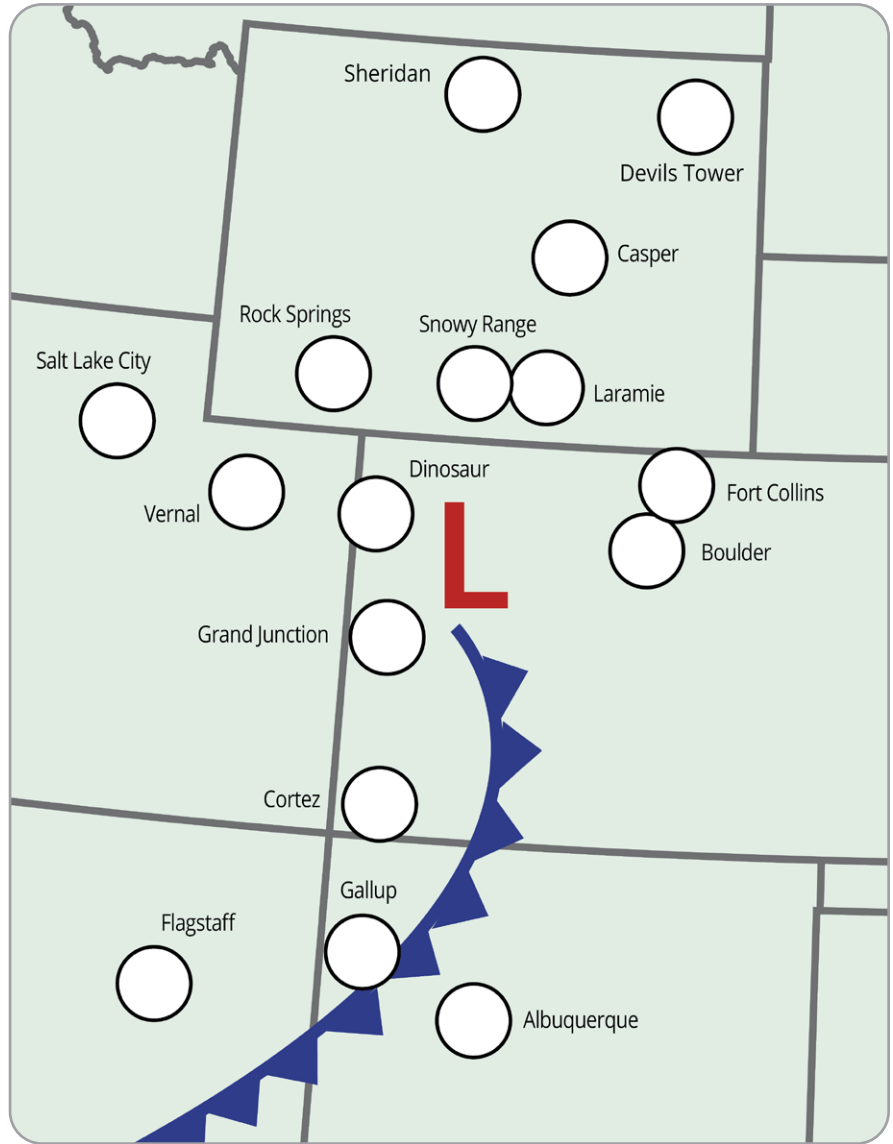
Below is the snowfall report for the communities shown on the map.

1. Locate the communities on the map and **write the snowfall** in the circles.

PART OF THE MODEL	SNOW (CM)
Rock Springs, WY	45.7
Laramie, WY	7.6
Snowy Range, WY	61.0
Sheridan, WY	1.3
Devils Tower, WY	0
Casper, WY	13.7
Dinosaur, CO	19.1
Grand Junction, CO	0
Fort Collins, CO	3.8
Boulder, CO	1.3
Cortez, CO	0
Flagstaff, AZ	0
Salt Lake City, UT	8.6
Vernal, UT	17.8
Gallup, NM	0
Albuquerque, NM	0



SNOWFALL: FEBRUARY 23, 2017



the center of an area of low pressure



cold front



STEP 2: Where might schools close?

Schools may close if there is heavy snowfall.

Locate where you think schools closed because of snow. **Color these locations with a bright color** on the map so you can easily see where the most snow occurred.



As the storm moved east, why did it snow in some areas but not others?

STEP 3: Look for a trend in the snowfall.

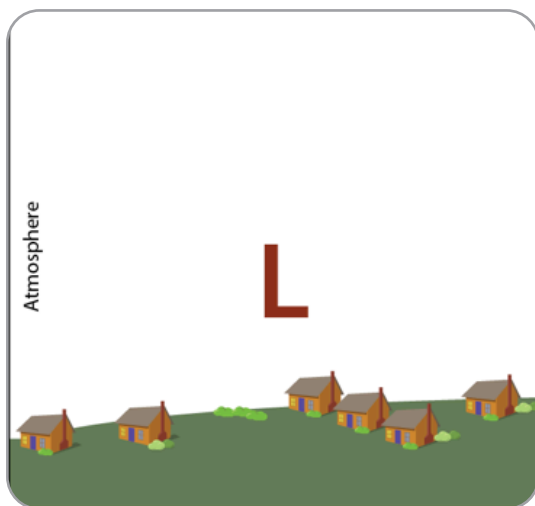
Refer to the map of snowfall on the previous page to answer the questions below.

1. What do you notice about the location of communities with the most snowfall? Where did the most snow fall with respect to the front and area of low pressure?
2. Why do you think this area received more snow?

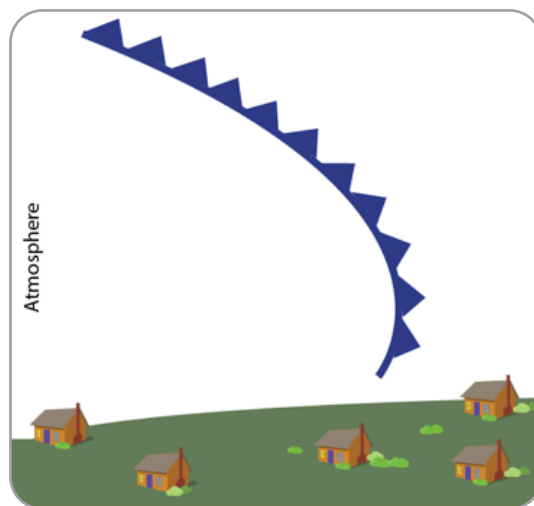
STEP 4: Why didn't it snow everywhere?

There are two things that a storm needs to cause precipitation:

1. Air that is rising and cooling and
 2. Enough moisture in the air to create clouds and precipitation.
1. **Draw a cross section** that shows how air is moving and where clouds are forming at an area of low pressure and at a cold front using models you developed as a class.



How air is moving and where clouds are forming **at an area of low pressure**



How air is moving and where clouds are forming **at a cold front**

2. Notice where there is low pressure and where the front is on the snowfall map. Remember that the storm came from the west, so it moved over the areas on the west side of the map before it got to this location.
 - **Circle locations on the snowfall map** where there was little or no snow.
 - Why do you think these locations didn't get much/any snow?
3. **Name the locations** that you think are too far from the storm to get much snow.

Moisture: When it was on the West Coast, this storm was full of moisture, which is what caused so much rain and snow. Is it still full of moisture? The amount of moisture in the air is measured as humidity. On the following page is the average humidity data for the communities shown on the map.

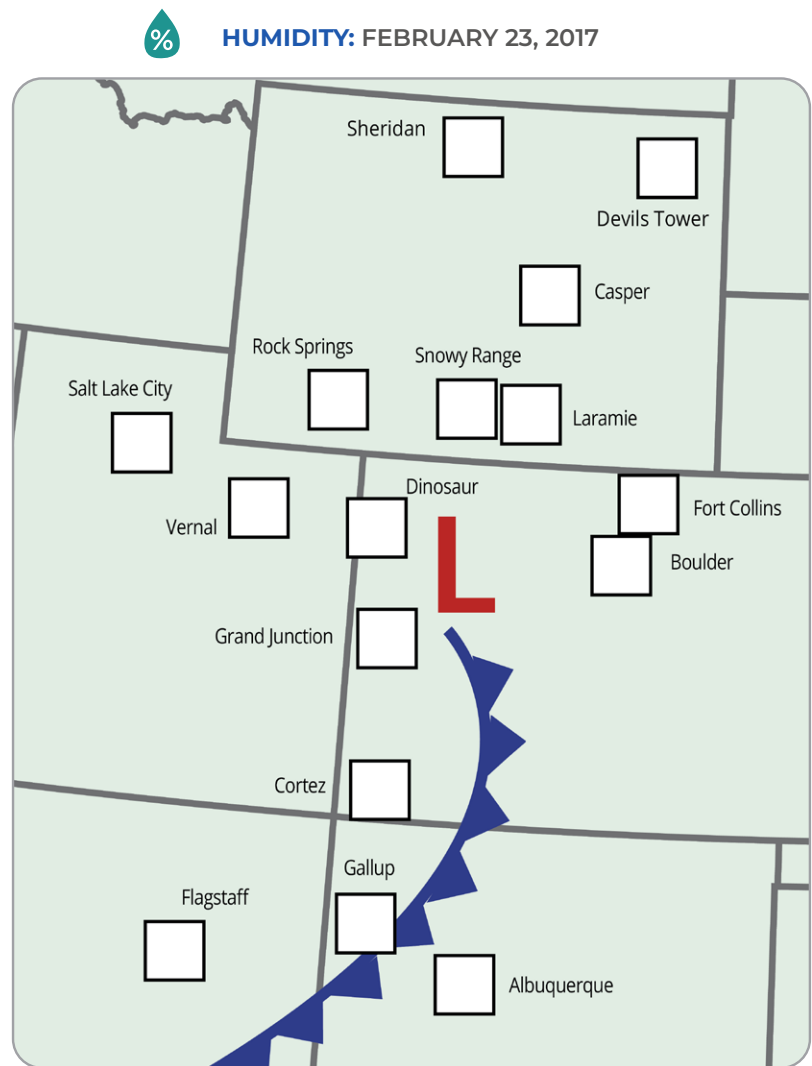


As the storm moved east, why did it snow in some areas but not others?

USE THESE DIRECTIONS BELOW TO CREATE THE HUMIDITY MAP.

1. The humidity measurements in the table are from near the ground, not up in the clouds, but they can help us estimate how much moisture is in the air. Locate the communities on the map and **write the humidity** in the squares using a different color than the snowfall measurements.
2. **Color code** the locations that had an average humidity under 70%. These locations are less likely to get precipitation. **Choose another color** for the locations with humidity over 70%. These locations are more likely to get precipitation.
3. Name the locations that you think didn't get much precipitation because the air didn't have enough moisture.

LOCATION	AVERAGE HUMIDITY (%)
Rock Springs, WY	81
Laramie, WY	77
Snowy Range, WY	77
Sheridan, WY	84
Devils Tower, WY	88
Casper, WY	92
Dinosaur, CO	90
Grand Junction, CO	62
Fort Collins, CO	85
Boulder, CO	85
Cortez, CO	58
Flagstaff, AZ	56
Salt Lake City, UT	81
Vernal, UT	90
Gallup, NM	43
Albuquerque, NM	33



KEY:

- the center of an area of low pressure
- cold front
- humidity under 70% (choose a color)
- humidity over 70% (choose a color)
- humidity



DISCUSS WITH YOUR CLASS.

How does the humidity data help you understand why it snowed in some places and not others?

CULMINATING TASK: Challenge 3

Where will schools have a snow day on February 24?

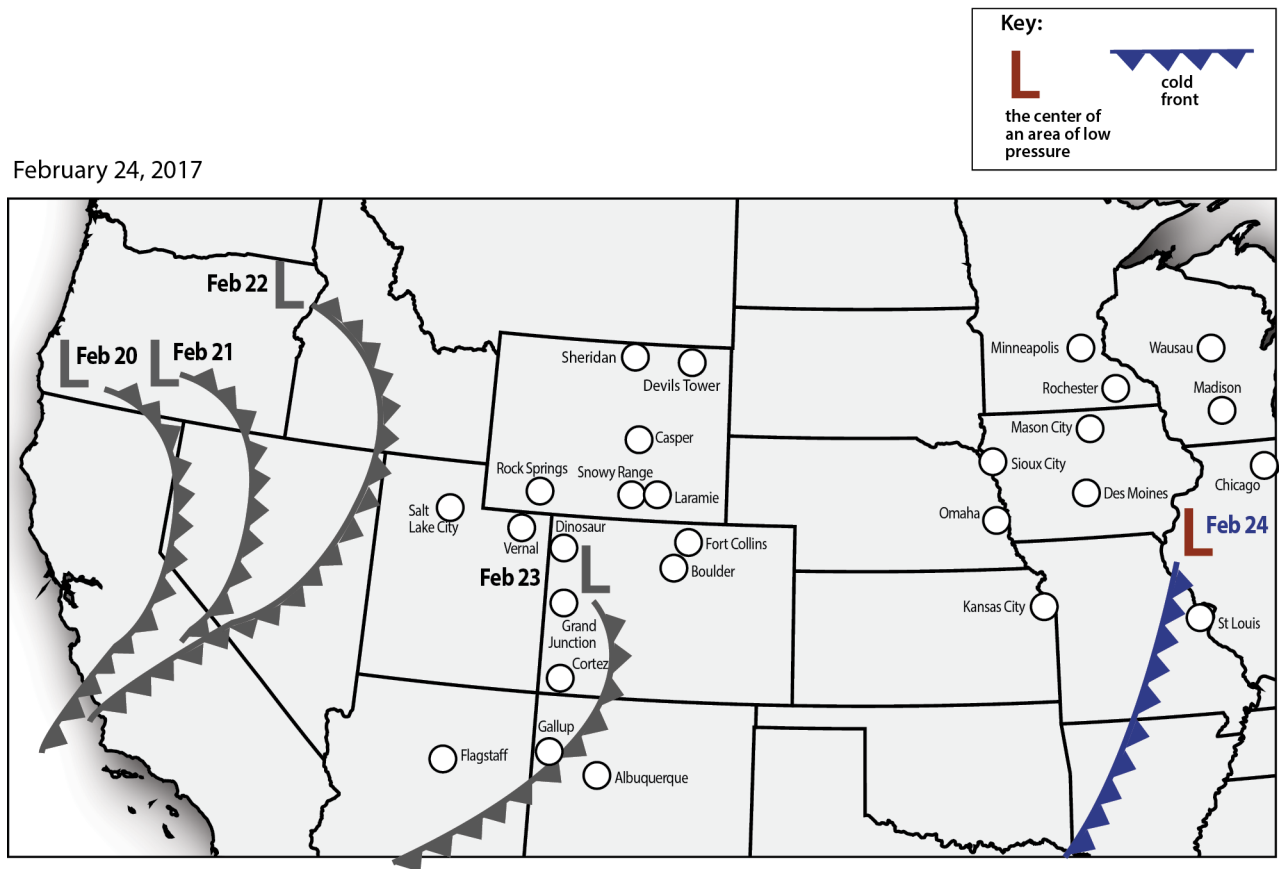
STEP 1: Consider where it snowed on February 23.

To predict the weather, meteorologists take into account what the weather was like the day before. In this case, you are the meteorologist. To predict where snow is likely to fall on February 24, you must take into account where this storm caused snow the day before (February 23).

Choose a color and fill in the circles where it snowed more than 5 cm on February 23 using the snowfall map from Challenge 2: Step 1. Leave circles without a color where little snow (5 cm or less) or no snow fell on February 23.



February 24, 2017



Where will schools have a snow day on February 24?



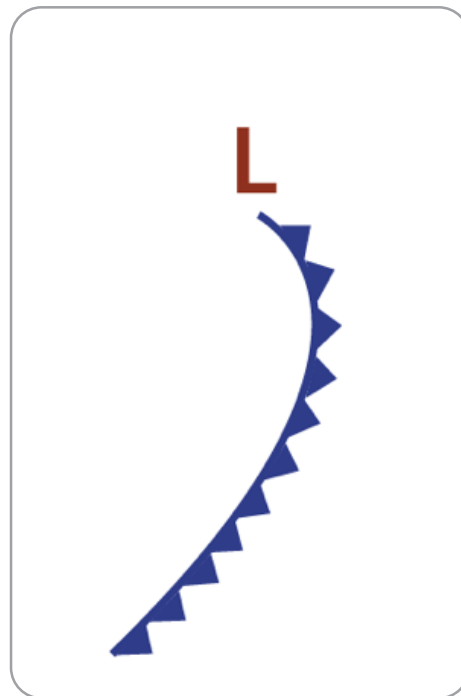
STEP 2: Where's the snow compared to the cold front and low pressure area?

Over North America, it's common for an area of low pressure to be located at the north end of a cold front. Looking at the map on the previous page, what do you notice about the location of the snow on February 23?

Draw the approximate location of snow in relationship to the location of the cold front and the area of low pressure on the diagram on the right.

1. How is the winter storm in this example similar to the cold front model that you developed? How is it different?

WHERE SNOW IS LIKELY:



STEP 3: Make a prediction for where it will snow on February 24.

Based on where the snow fell during this storm on February 23, where do you think snow will fall on February 24?

1. **Color in the circles** for towns on the February 24th weather map where you think it will snow more than 5 cm.
2. **Write the names** of the locations below and explain why the locations would receive precipitation.

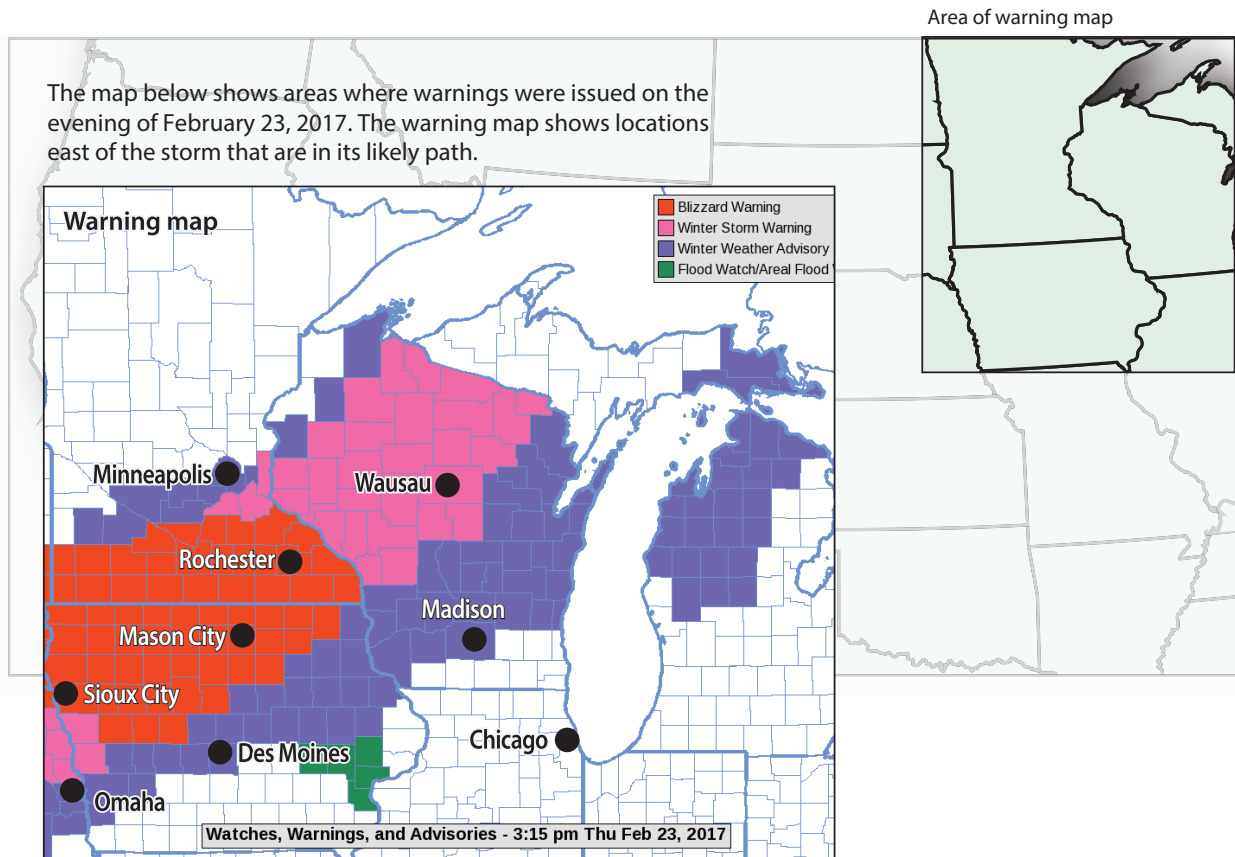


Where will schools have a snow day on February 24?

STEP 4: Warning Map.

The map below shows areas where warnings were issued on the evening of February 23, 2017. The warning map shows locations east of the storm that are in its likely path.

- **A Blizzard Warning** is issued for winter storms with winds of 35 mph or higher and heavy, blowing snow.
- **A Winter Storm Warning** is issued when a winter storm is expected within 36 hours with at least 4 inches (10 cm) of snow or at least 3 inches (7.6 cm) of snow and large amounts of ice.
- **A Winter Weather Advisory** is issued when a low pressure system produces a combination of winter weather (snow, freezing rain, or sleet) that presents a hazard.
- **A Flood Watch** is issued when conditions are favorable for flooding.



Where will schools have a snow day on February 24?

IS IT A SNOW DAY?

Depending on where you live, you might have felt the excitement when snow is in the forecast. Sure, snow is fun no matter when it happens, but when it happens on a school day and school is canceled, that's particularly exciting.

School officials must decide if they're going to cancel school or delay classes. Their job is to keep people safe. How do they make that decision?

In places where snow is rare, like the southeast U.S., a weather forecast that includes any snow and ice might be enough to cause schools to close. These places often don't have snow plows or trucks that add salt or sand to the roads to melt ice. This means that it doesn't take much to make the roads and sidewalks unsafe.

In places where snowy weather is common, towns and cities usually have plans for dealing with it. Schools often do not close for snow if the roads and sidewalks can be cleared. However, schools do close for extreme cold temperatures so that students are not waiting for the bus or walking to school when the temperature is below freezing. Schools might also close if snow is blowing, which reduces visibility.

Many types of weather information are important for school officials to decide whether to cancel school including the timing of the storm, the temperature, the amount of snow, and the amount of wind. School officials take into account whether the National Weather Service has issued weather watches, warnings, or advisories.



1. What locations should cancel school based on the reading above and your predictions of snowfall from Step 3?



STEP 5: Discuss with the class.

Talk with your classmates. Does everyone have the same hypothesis about where it will snow on February 24? Look at where the most snow (more than 15 cm) fell on February 23 and decide which locations might close schools and workplaces on February 24. Take the warning map into account.





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ASSESSMENTS



THE GLOBE PROGRAM

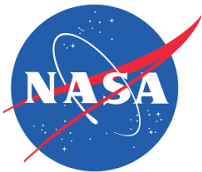


BSCS
SCIENCE LEARNING





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ASSESSMENTS

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TEACHER GUIDE

TEACHER GUIDE



TYPES OF GLOBE WEATHER ASSESSMENTS



Types of GLOBE Weather Assessments

EMBEDDED PRE-ASSESSMENT

The table below outlines two opportunities for pre-assessment in Lesson 1 and suggests what evidence of student thinking and prior knowledge to look for during the lesson.

LESSON 1 PRE-ASSESSMENT OPPORTUNITIES:	LOOK FOR:
<p>1 Teacher Guide: 3-4 of “Introduce the Anchoring Phenomenon”</p> <p>(Student: Lesson 1, Step 1)</p>	<ul style="list-style-type: none"> words and scientific terms they use to describe the water cycle (e.g., evaporation, precipitation and condensation) or expression of these ideas without using these terms. whether they focus mostly on water moving places or whether they also include sunlight, heat, temperature, or other references to energy.
<p>1 Teacher Guide: 1 of “Modeling Storm Formation”</p> <p>(Student: Lesson 1, Step 3)</p>	<ul style="list-style-type: none"> the water cycle processes students include in their diagram (e.g., evaporation, condensation, precipitation). whether they use water molecules or a generic macroscale representation of water in their drawing. whether they include references to sunlight, heat, or energy as a mechanism for moving water around the water cycle.

FORMATIVE ASSESSMENT

Each lesson includes a variety of opportunities for formative assessment that correspond to particular parts of the instruction. The table (pages 3-5) summarizes notable formative assessment opportunities focused on three-dimensional learning outcomes that are tied to each lesson and work toward the NGSS Performance Expectations for the unit. Also, Exit Tickets, used at the end of each lesson to inform your instructional decision-making for the subsequent lesson, are listed in the table.

LEARNING SEQUENCE SUMMATIVE ASSESSMENTS

Each learning sequence has a corresponding summative assessment (pages 7-17) composed of open response questions that prompt students to use their knowledge of disciplinary core ideas and crosscutting concepts as well as engage in the science practices of data analysis and interpretation and modeling. You can use the provided interpretive answer keys to make sense of student learning and to identify productive thinking and counterproductive, incomplete, and inaccurate ideas. The interpretive answer keys suggest where you can revisit instruction based on incomplete and inaccurate student thinking.

FINAL ASSESSMENT

Intended for the end of the unit, the final assessment (pages 18-21) targets fundamental science ideas learned in the unit as well as the NGSS science practices of data analysis and interpretation and modeling. The assessment also prompts students to share what they know about the NGSS crosscutting concepts of patterns and cause and effect.

LESSON	PERFORMANCE OUTCOMES	FORMATIVE ASSESSMENT OPPORTUNITIES	EXIT TICKET SUGGESTIONS
<p>LESSON 2</p>	<p>Develop a model to describe how clouds form during a day and build until they form a rainstorm.</p>	<p>Teacher Guide: “Diagram a Storm Forming” (Student: Step 3)</p> <p>Look for:</p> <ul style="list-style-type: none"> • student connections to temperature changes over the course of the day or between the ground and clouds. • student explanations about the role of sunlight or energy from the Sun in the storm formation. • water cycling processes like evaporation and condensation. 	<ul style="list-style-type: none"> • Write one idea or concept that you found particularly interesting or important about how a small cloud changes into a storm—the “What?” • Write why that concept or idea is important—the “So what?” • Think about how your thinking has changed based on that new idea—the “Now what?”
<p>LESSON 3</p>	<p>Collect data and analyze data to identify patterns that describe the relationship between temperature and altitude.</p> <p>Analyze and interpret data to describe differences in surface temperature and air temperature during a day.</p>	<p>Teacher Guide: “Collect Temperature Data” (Student: Steps 1-3)</p> <p>Look for:</p> <ul style="list-style-type: none"> • students explaining why the ground could be warmer than the air above it. (Listen attentively to whether students explain that the air is heated from the Sun from above or from the ground below.) • students connecting warmer temperatures at the surface with evaporation of water and cooler temperatures near the clouds with condensation. <p>Teacher Guide: “Model: Heating Earth’s Atmosphere” (Student: Steps 5-6)</p> <p>Look for:</p> <ul style="list-style-type: none"> • students describing the pattern that temperature decreases as altitude increases. • students adding ideas consistent with the temperature data and with the underlying mechanisms that explain temperature differences. • students using data to explain temperature differences from the ground to the cloud. • students explaining that heating of the surface by the Sun causes warming of air and evaporation of water, which eventually leads to the storm. 	<ul style="list-style-type: none"> • What questions from the Driving Question Board can we now answer, and how would we answer them? • What new questions do you have? • What parts of the Colorado storm can we explain with our ideas right now?

LESSON	PERFORMANCE OUTCOMES	FORMATIVE ASSESSMENT OPPORTUNITIES	EXIT TICKET SUGGESTIONS
4	<p>Analyze and interpret data to identify differences in patterns in air temperature and humidity during stormy days and sunny days.</p> <p>Conduct an experiment and collect and analyze data to compare changes in humidity in sunny and in stormy conditions.</p>	<p>Teacher Guide: “Data Analysis: Sunny and Stormy Day” (Student: Steps 1-2)</p> <p>Look for:</p> <ul style="list-style-type: none"> students identifying that rising temperature paired with high humidity increases the chance of storms. students identifying that rising temperature with falling humidity decreases the chance of storms. students identifying that humidity is a critical component of the system. <p>Teacher Guide: “Bottle Model Lab” (Student: Step 3)</p> <p>Look for:</p> <ul style="list-style-type: none"> students connecting the sunny day and stormy day graphs with the observations of bottle models. students identifying the pairing of warm temperatures and high humidity with increased chances of afternoon storms. students realizing that the reason storms happen in the afternoon is due to the time needed to warm the air and evaporate water from the surface. 	<ul style="list-style-type: none"> How did the water from the bottom of the bottle get up on the sides of the bottle?
5	<p>Develop and use a model to explain how energy from the Sun, convection, water on the surface and in the air, and variations in temperature and humidity create conditions/cause the formation of isolated storms.</p>	<p>Teacher Guide: “Consensus Model” (Student: Steps 3-6)</p> <p>Look for:</p> <ul style="list-style-type: none"> students sharing ideas about warm air from the surface rising and then cooling near the clouds. students sharing ideas about warm air holding more moisture near the surface that condenses when it reaches cooler temperatures near the clouds. the possible student misconception that warm air is located closer to the Sun. progress in students representing science ideas in their models and the accuracy of the models. students including all the required information listed in the checklist in the instructions located at the top of their models. students using model ideas in their written explanations, particularly those related to heating of the surface and air, the connection between temperature and water cycling processes, and the conditions of warm, rising air with moisture, which are necessary for a storm. 	<ul style="list-style-type: none"> How could we test whether our model can help us predict when precipitation happens in an isolated storm?
6	<p>Collect, analyze, and interpret data to describe temperature and humidity conditions on the ground and in the clouds that create conditions/ cause the formation of a storm.</p>	<p>Teacher Guide: “When Did It Rain?” (Student: Step 3)</p> <p>Look for:</p> <ul style="list-style-type: none"> accuracy of student ideas. which model ideas students use and do not use in their explanations. whether students are supporting their explanations with evidence and/or model ideas. 	<ul style="list-style-type: none"> Describe a storm you’ve experienced that doesn’t fit our model.

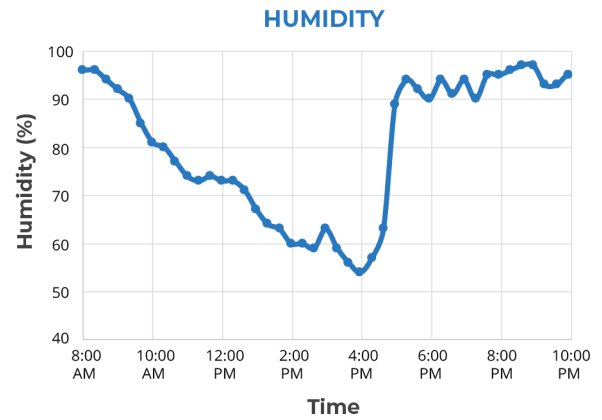
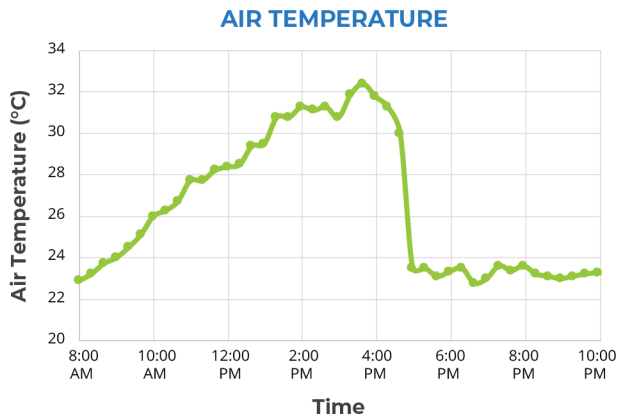
LESSON	PERFORMANCE OUTCOMES	FORMATIVE ASSESSMENT OPPORTUNITIES	EXIT TICKET SUGGESTIONS
LESSON 7	Use a model to make predictions about characteristics of air before, during, and after a cold front.	<p>Teacher Guide: “What’s a Cold Front Like?” (Student: Step 3)</p> <p>Look for:</p> <ul style="list-style-type: none"> students using model ideas from LS1 to help them explain their initial observations of the cold front. 	<ul style="list-style-type: none"> Use what you know now to draw a temperature graph for one day before the front, the day the front arrives, and the day after the front. Explain why you drew the graph the way you did.
LESSON 8	Analyze graphs to describe the changes in temperature and humidity before and after a cold front.	<p>Teacher Guide: “Model Idea Tracker Discussion”</p> <p>Look for:</p> <ul style="list-style-type: none"> students explaining how the regular diurnal pattern gets disrupted before the front and returns after the front, but it’s colder. students explaining temperature patterns starting warmer and getting colder after the front. students explaining humidity starting high and becoming low after the front. students connecting some of their understandings about what causes an isolated storm to what causes precipitation along a cold front, such as high humidity. 	<ul style="list-style-type: none"> What questions on the Driving Question Board can we now answer, and how would we answer them? What new questions do you have? What parts of the Colorado storm can you explain with our ideas right now?
LESSON 9	Develop a model to show how differences in temperature and humidity before and after a cold front interact to cause a storm.	<p>Teacher Guide: “Consensus Model: Precipitation along a Cold Front” (Student: Step 3)</p> <p>Look for:</p> <ul style="list-style-type: none"> progress in students representing science ideas in their models and the accuracy of the models. students including all the required information noted in the model checklist. <p>(Student: Step 5)</p> <p>Look for:</p> <ul style="list-style-type: none"> students using model ideas in the written explanation, particularly those related to temperature differences in air masses, cold air pushing warm air up, and warm air having high humidity and condensing to form precipitation. 	<ul style="list-style-type: none"> How could we test whether our model can help us predict precipitation along a cold front?
LESSON 10	Analyze patterns in data to describe how pressure changes before and after a cold front.	<p>Teacher Guide: “Pressure: Data Analysis”</p> <p>Look for:</p> <ul style="list-style-type: none"> students sharing ideas that air pressure is higher before a cold front and lower just before and during the storm. students connecting ideas about air pressure with air temperature and humidity. 	<ul style="list-style-type: none"> Write down an initial list of model ideas you believe will help you explain the Colorado storm. What questions do you still have about the Colorado storm?

LESSON	PERFORMANCE OUTCOMES	FORMATIVE ASSESSMENT OPPORTUNITIES	EXIT TICKET SUGGESTIONS
LESSON 11	<p>Develop a model to show how differences in pressure cause the movement of moisture that leads to a storm.</p>	<p>Teacher Guide: “Explaining the Colorado Storm” (Student: Steps 2-3)</p> <p>Look for:</p> <ul style="list-style-type: none"> accuracy of student ideas. which model ideas students use and do not use in their explanations. whether students are supporting their explanations with evidence and/or model ideas. 	<ul style="list-style-type: none"> What questions on the Driving Question Board can we now answer, and how would we answer them? What new questions do you have? What parts of the Colorado storm can you explain with our ideas right now?
LESSON 12	<p>Make observations to describe the large-scale motion of water in the atmosphere.</p> <p>Describe patterns of how water moves through the atmosphere around the world.</p>	<p>Teacher Guide: “Global Precipitation Patterns” (Student: Steps 3-4)</p> <p>Look for:</p> <ul style="list-style-type: none"> students connecting patterns to observations from the video. students describing patterns of east-west precipitation movement, curling or spinning patterns, and patterns of regular cloud cover in some areas but not others. 	<ul style="list-style-type: none"> What questions do you have about how precipitation moves around the world? What have you learned about what causes storms to move that might help explain these patterns of global precipitation movement?
LESSON 13	<p>Analyze a model to describe latitudinal variations in the concentration of sunlight and to explain variations in temperature.</p> <p>Analyze data to describe global patterns in average annual temperatures.</p>	<p>Teacher Guide: “Energy Angles” (Student: Step 3)</p> <p>Look for:</p> <ul style="list-style-type: none"> whether students connect the angle of rays to the concentration of solar radiation at the equator and poles. students connecting the concentration of solar radiation with global temperature patterns. <p>Teacher Guide: “Temperature Data Investigation” (Student: Step 4)</p> <p>Look for:</p> <ul style="list-style-type: none"> students understanding that average annual temperatures are consistently warmer near the equator. Temperatures, on average, are cooler near the poles, and there is seasonal variation. (Note: It is not important for students to recognize seasonal shifts in temperature). 	<ul style="list-style-type: none"> How do average temperatures where you live compare to temperatures in Sri Lanka and why?
LESSON 14	<p>Develop a model to show how air is circulating through the atmosphere in the tropics and midlatitudes.</p>	<p>Teacher Guide: “Develop a Working Model” (Student: Step 1)</p> <p>Look for:</p> <ul style="list-style-type: none"> students connecting warmer temperatures to areas of rising air and cooler temperatures to areas of sinking air. <p>Teacher Guide: “Global Air Circulation Diagram” (Student: Step 5)</p> <p>Look for:</p> <ul style="list-style-type: none"> students making connections between convection concepts they learned about in LS1 and LS2, the relationship between convection patterns and global temperature patterns, and the locations of areas of high and low air pressure and the resulting moisture or precipitation patterns. 	<ul style="list-style-type: none"> How could we test whether our model can help us predict storm movement in the tropics?

LESSON	PERFORMANCE OUTCOMES	FORMATIVE ASSESSMENT OPPORTUNITIES	EXIT TICKET SUGGESTIONS
<p>LESSON 15</p>	<p>Use knowledge of patterns in surface winds to make a prediction of the movement of a storm.</p>	<p>Teacher Guide: “Explaining Storm Movementtudent: Step 3)</p> <p>Look for:</p> <ul style="list-style-type: none"> • which model ideas students use and do not use in their explanations. • whether students are supporting their explanations with evidence and/or model ideas. • students connecting the storm movement to understandings of both global air circulation and the Coriolis effect. 	<ul style="list-style-type: none"> • What questions on the Driving Question Board can you now answer, and how would we answer them? • What new questions do you have? • What parts of the Colorado storm can you explain with our ideas right now?

Learning Sequence 1 Assessment: Isolated Storms

An isolated storm happened in Rockwall, Texas on August 26, 2017. The graphs below show how humidity and air temperature changed during the day. Use the data in the graphs below to answer the following questions.



1. What time do you think the storm occurred? Explain your reasoning using the temperature and humidity data.

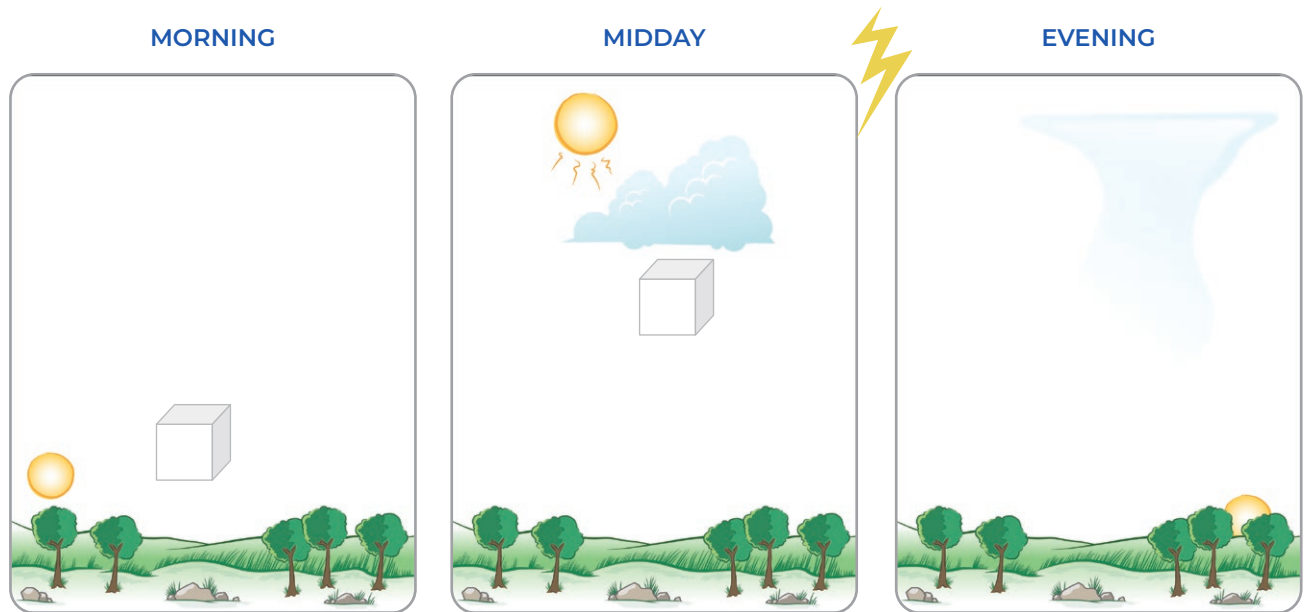
2. Sunrise in Rockwall, Texas, was at 6:57 a.m. on August 26. Explain why the air temperature changed the way it did from between 8:00 a.m. and 12:00 p.m.

3. The air temperature was measured about one meter above the ground. Draw a line on the air temperature graph to show how you think the temperature of the ground changed over the day. Then, explain why you think the surface temperature would change like this.

- The air temperature near the surface is different from the air temperature higher in the atmosphere. Explain how they are different and why this difference is necessary for a storm to form.

The pictures below show one location at three different times during one day: morning, midday, and evening. The day was sunny in the morning and then a thunderstorm formed around 3:00 p.m., which lasted an hour.

The boxes in the pictures represent a “pocket” of air that moves over time. In the morning, the air is near the ground. At midday (12:00 p.m.), the pocket of air has moved higher in the atmosphere. Answer the questions below to complete the model and to explain what it shows about the thunderstorm.



- Draw a box to show where you think the pocket of air might be on the “Evening” diagram.
- Explain why you put the box where you did.

7. Do you think the temperature and humidity of the air in the box is increasing, decreasing, or staying the same during the morning and midday (just before storm)? Circle your answers for each time in the table to the right.

	TEMPERATURE	HUMIDITY
MORNING	Increasing Decreasing Staying the same	Increasing Decreasing Staying the same
MIDDAY	Increasing Decreasing Staying the same	Increasing Decreasing Staying the same

Explain why you think the temperature and humidity would change like this during the morning and then midday, just before the isolated storm occurred.

1. One student claims that the box would get larger between morning and midday, assuming that the molecules can't escape from the box. Do you agree or disagree? Explain your reasoning.
2. Another student claims that if there was another box of air high in the atmosphere at midday, it would be colder than the air below so it would sink toward the ground. Do you agree or disagree? Explain your reasoning.
3. Use what you learned about temperature and humidity patterns on a stormy day to explain why the storm happened in the afternoon instead of the morning.
4. Describe how energy from the Sun helps to cause the storm.

Learning Sequence 2 Assessment: A Front Headed Your Way

Map 1, to the right, shows maximum air temperatures ($^{\circ}\text{C}$) across the northeastern United States on June 28, and Map 2 shows humidity (%).

Weather forecasts **for the next day** (June 29) in central Pennsylvania (shown on the maps with a star ★) predict the following:

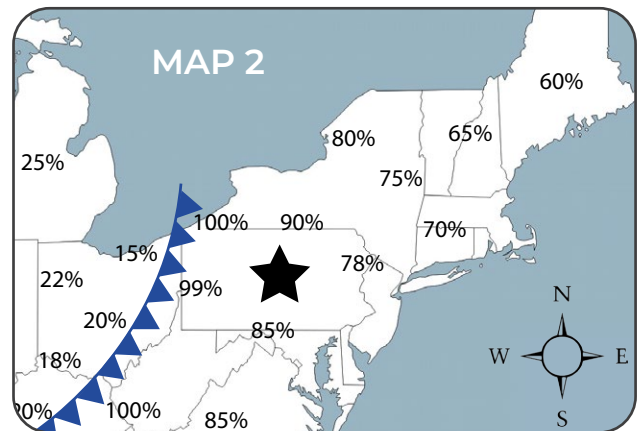
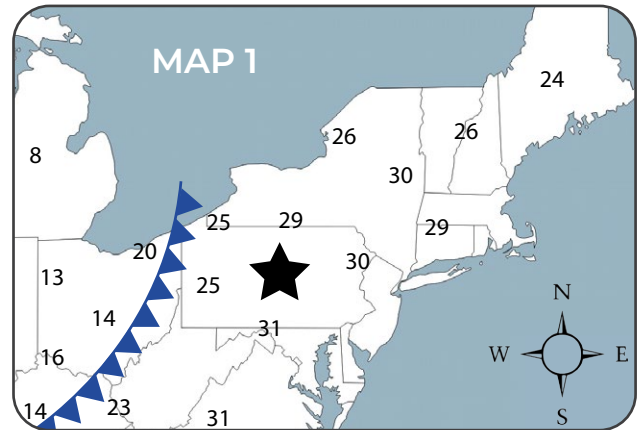
▶ Temperatures will drop to $15\text{--}20^{\circ}\text{C}$, and storms are likely by the afternoon.

Answer the following questions to explain how weather forecasters used the data in these maps to decide that a storm is coming to central Pennsylvania.

- The line with the triangles on each map shows the location of a cold front. Describe the temperature and humidity of the air on both sides of the front.

East of the front (to the right of the front on the map):

West of the front (to the left of the front on the map):

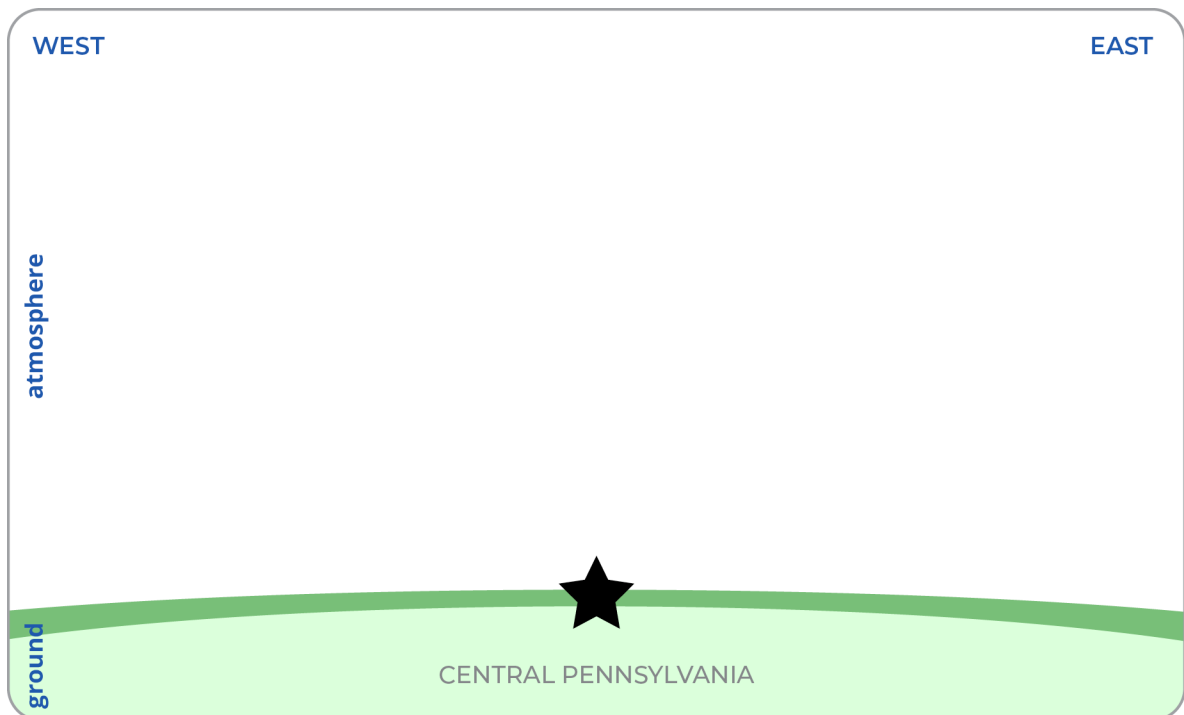


- Using what you know about the air on both sides of the front, describe how air is moving at the front.

3. Draw an **L** to show where you would expect to find the lowest air pressure on a map on the previous page and an **H** to show where you would expect to find the highest air pressure. Explain why you put the **H** and the **L** where you put them.

4. Describe how you'd expect air pressure to change in central Pennsylvania (shown with a star ★ on the maps on the previous page) from June 28 to June 29 as the cold front moves through. Explain your reasoning.

5. Draw a cross-sectional model below to show how the air masses will interact along the cold front as it moves through central Pennsylvania (shown with a star ★) on June 29. Your model should:
 - show the location of the cold front.
 - show the location of air masses (and note the temperature, humidity, and air pressure).
 - use arrows to show how air is moving.
 - indicate where a storm is likely to form.



6. How can the movement of the air shown in your cross-sectional model cause a storm? Explain your reasoning.

7. Add an **H** to your cross-sectional model to show where air pressure would be highest and an **L** where air pressure would be lowest. How do these differences in air pressure cause the air to move?

8. Use your model and the temperature and humidity data on the maps to explain why it will likely rain in central Pennsylvania (star ★).

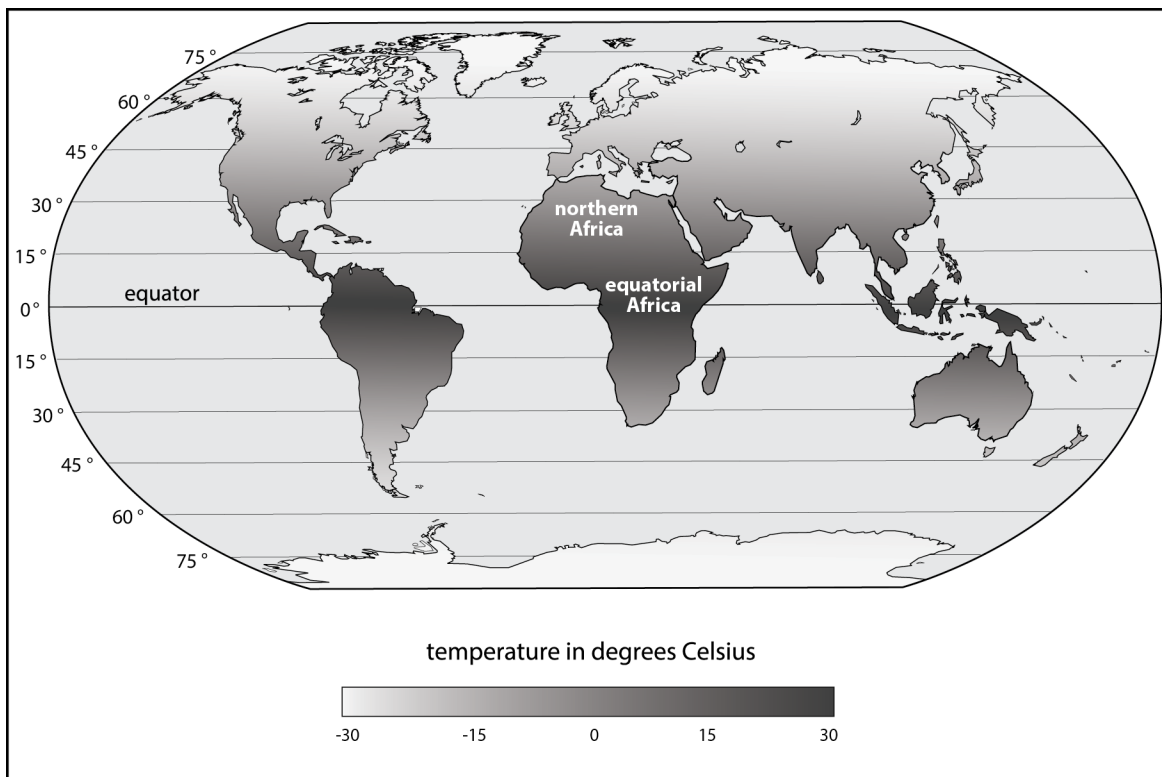
9. In the table below, describe two similarities and two differences in how isolated storms and cold front storms form.

SIMILARITIES		DIFFERENCES
1		
2		

Learning Sequence 3 Assessment: Worldwide Weather

Northern Africa is very dry and receives very little rainfall throughout the year. However, equatorial Africa has many storms, meaning a lot of rainfall. Examine the map below.

MAP 1. AVERAGE ANNUAL TEMPERATURE AROUND THE GLOBE.

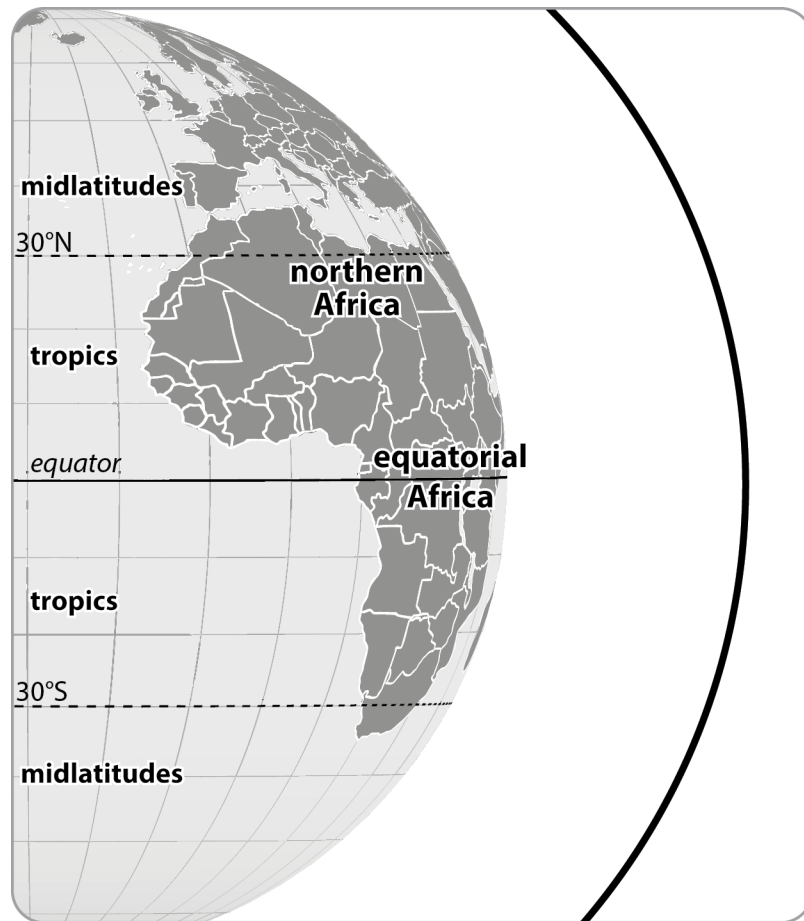


1. Answer the questions to explain what causes the different temperature patterns in the map above.
 - a. Compare the average annual temperature in equatorial Africa to the average annual temperature in northern Africa.

 - b. Explain why the average annual temperatures are different in these two regions.

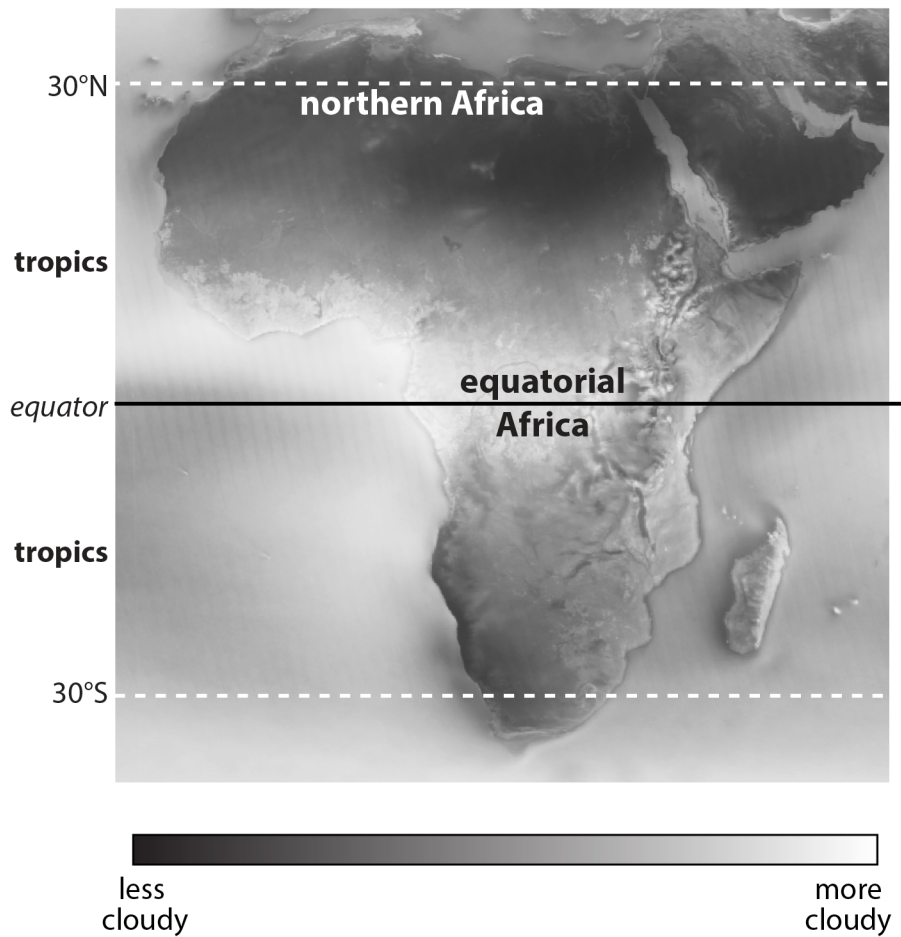
2. Draw on the cross-section below to show what is happening in the atmosphere above Africa. Focus on the tropics, which are between 30°N and 30°S latitude.
 - a. Use arrows to show how air moves from the equator to the midlatitudes (from 0° to 30°N and also from 0° to 30°S).
 - b. Draw clouds where you would expect to find the most cloud cover in the atmosphere above Africa.
 - c. Add **H** for areas of high pressure and **L** for areas of low pressure.

AIR MOVEMENT IN THE ATMOSPHERE ABOVE AFRICA.



3. Explain how different average annual temperatures in the tropics and midlatitudes help cause the different patterns in air circulation in the two regions you drew in the cross-section above.

MAP 2. PERCENT OF AVERAGE ANNUAL CLOUD COVER OVER AFRICA FROM 2002 TO 2015.

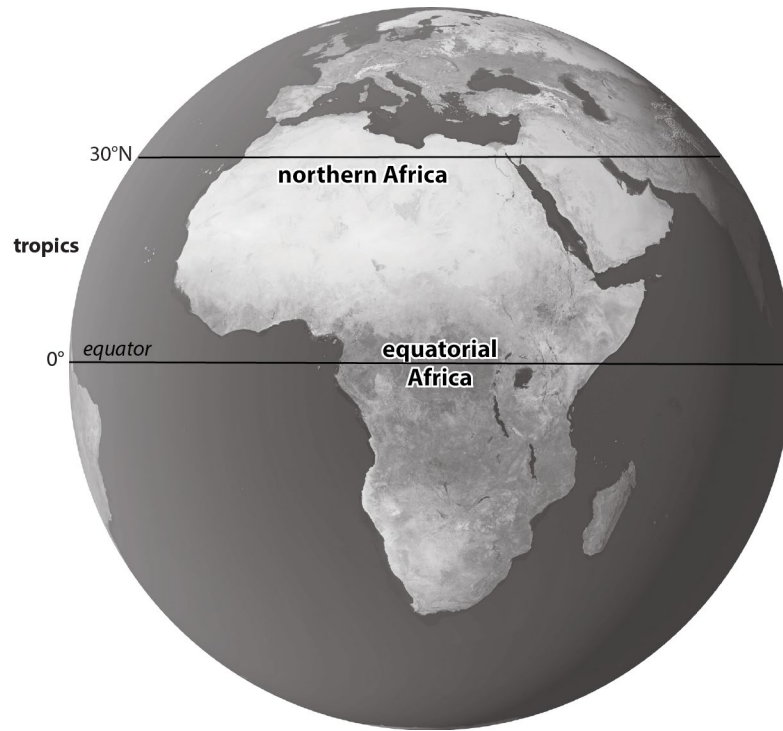


4. Examine map 2 above, which shows cloud cover.

Use what you know about how clouds form and the patterns in air circulation in the tropics to explain why there are fewer clouds in northern Africa.

5. Storms in tropical Africa generally do not move directly north from the equator toward northern Africa. Draw on the image below to explain the movement of storms in this part of the world.
- At 30°N, winds spread out across Earth's surface. Draw the direction that winds would travel north and south of 30°N if the Earth was not spinning.
 - Use a different color to draw how winds actually curve north and south of 30°N due to the Coriolis effect.

DIRECTION OF WIND IN NORTHERN AND EQUATORIAL AFRICA

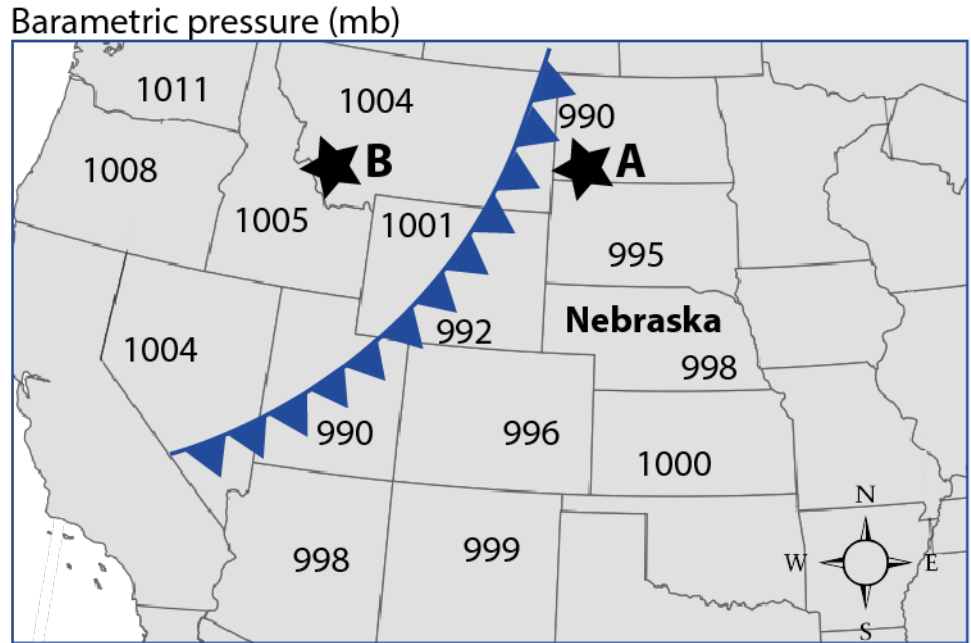


- Use what you know about the direction of winds to explain why storms in tropical Africa do not move directly north from the equator toward northern Africa.

A school in Nebraska is planning a graduation party for a day in May. One day before the party, weather forecasters warned:

▶ Even though it is warm and sunny now, a cold front will soon move into Nebraska.
 ▶ Tomorrow the weather will become cool and rainy.

The weather forecasters used air pressure data (measured in millibars; shown on the map below) to predict more precisely how the front will move.



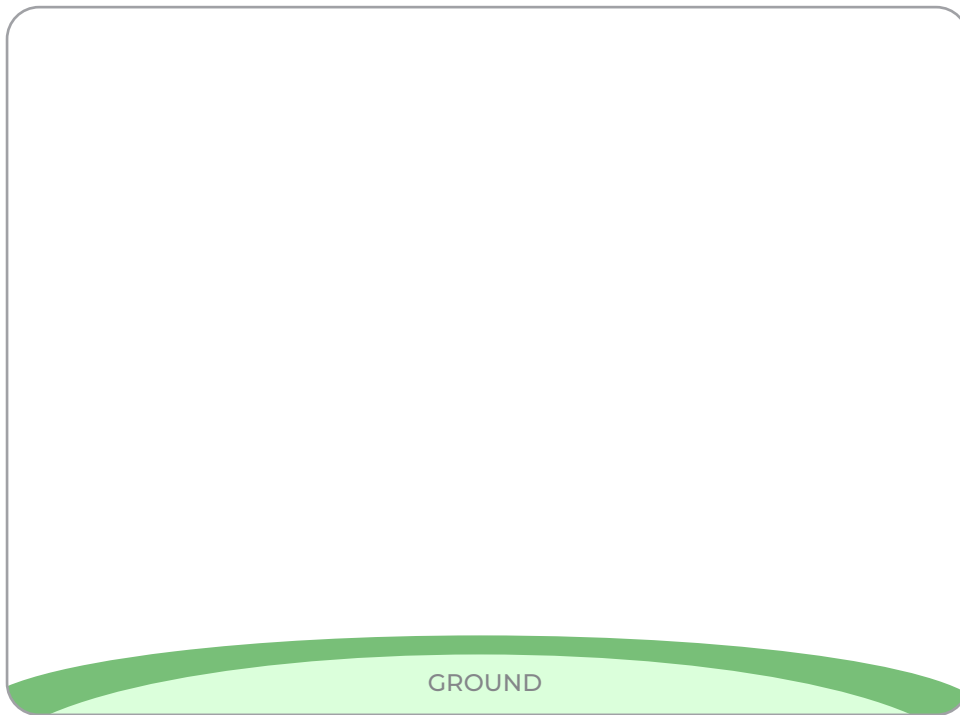
3. Use the air pressure data and cold front shown in the map to describe how air is moving at location A. Explain why it moves this way. Now describe how the air is moving at location B. Explain why it is moving this way.

4. Use the air pressure data and your knowledge about how air is moving at locations A and B to explain *why* weather forecasters predict that the front will *likely* move to Nebraska.

5. Think about the temperature of the air masses that make up a cold front and the air pressure data from the map on the previous page. When the cold front arrives in Nebraska, what will happen to the warm air that is there now? **Draw and label a cross-sectional model in the box below** to show how the air masses will interact.

Your model should show:

- the warm air mass
- the cold air mass
- the location of the cold front
- the direction that the cold front is moving
- what causes the cold front to move this way

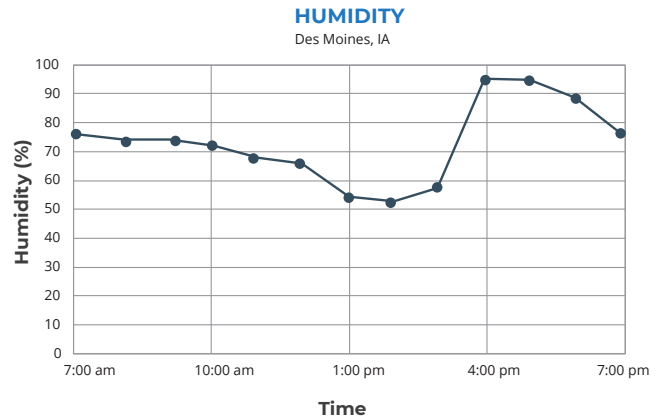
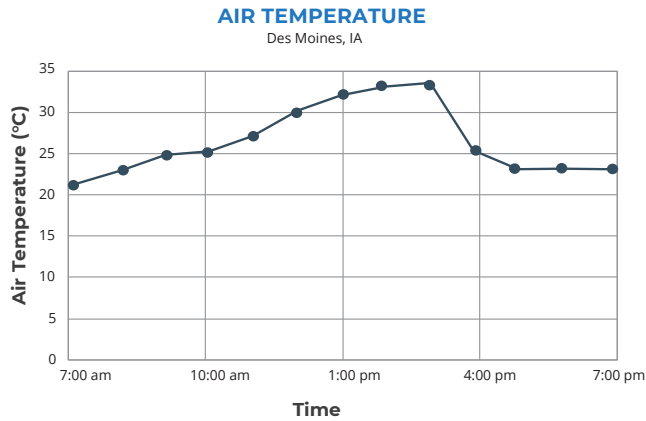


Add arrows, labels, and use color to help you explain what happens to the two air masses in your model.

6. Explain *why* the warm air and cold air will move the way you showed in your model.
7. Before the cold front moved into Nebraska, students noticed it felt very muggy or humid. Use your model to explain *why* it will probably rain in Nebraska during the graduation party.

8. A school in Des Moines, Iowa has a similar problem. On graduation day, there was a thunderstorm around 4:00 p.m. that ended about an hour later.

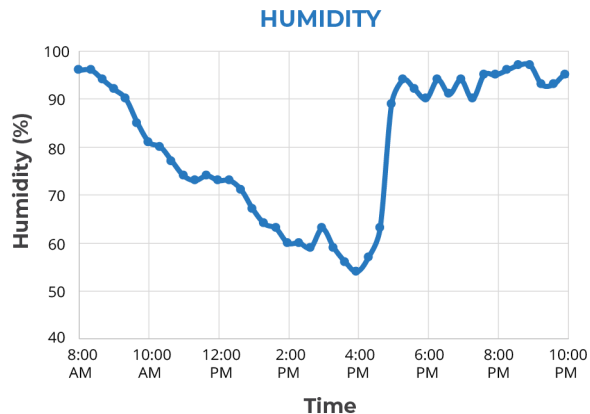
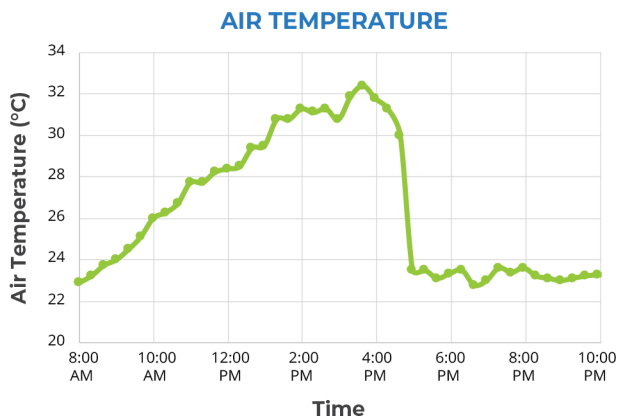
Use the air temperature and humidity data in the graphs below to analyze the storm.



- a. Think about how air temperature and surface temperature are different. Scientists reported that ground surface temperature at 7:00 a.m. was 23°C. **Draw a new line on the air temperature graph above** to show how the surface temperature changes during the day.
- b. Explain why ground surface temperature would follow the line that you drew.
9. Use the temperature and humidity data in the graphs above to explain why it rained in the afternoon.

Learning Sequence 1 Assessment: Isolated Storms

An isolated storm happened in Rockwall, Texas on August 26, 2017. The graphs below show how humidity and air temperature changed during the day. Use the data in the graphs below to answer the following questions.



1. What time do you think the storm occurred? Explain your reasoning using the temperature and humidity data.

Performance Outcome: Analyze and interpret data to support reasoning about the relationship between changes in temperature and humidity and storms.

Indicators of progress

- Students identify that the storm happened between 4:00 p.m. and 5:00 p.m. Students explain that at this time air temperature decreased and humidity increased, which indicate the storm.

Incomplete or inaccurate ideas

- Students identify any other time period for the storm.
- Students do not identify high humidity as a key factor.
- Students may focus more on temperature than humidity.

Suggestions: Revisit the sunny day and stormy day graphs from Lesson 4. Ask students why low humidity would not be a good condition for a rainstorm. Ask students what happens to surface water (lakes, ocean, rivers, soil moisture) when temperatures warm up during the day (evaporation).

2. Sunrise in Rockwall, Texas, was at 6:57 a.m. on August 26. Explain why the air temperature changed the way it did from between 8:00 a.m. and 12:00 p.m.

Performance Outcome: Analyze and interpret data to support reasoning about the relationship between changes in energy from sunlight during a day and changes in air temperature during a day.

Indicators of progress

- Students identify that when the Sun rises, it warms the Earth's surface (the ground). The longer the Sun is overhead, the more the ground and the air above the ground warms up. That is why there is a slow increase in temperature during the morning.

Incomplete or inaccurate ideas

- Students focus on Sun warming air molecules directly from above.
- Students focus on air temperature being affected mostly by cloud cover and not linking to the warming of the surface.

Suggestions: Revisit the Longmont temperature measurements in Lesson 3. Talk about what happens when energy from the Sun reaches Earth.

3. The air temperature was measured about one meter above the ground. Draw a line on the air temperature graph to show how you think the temperature of the ground changed over the day. Then, explain why you think the surface temperature would change like this.

Performance Outcome: Draw a graph to show how surface temperature data would be different from temperature data higher above the ground.

Indicators of progress

- Students correctly draw the surface temperature data mirroring (at least mostly) the air temperature data, with surface temperature warmer than air temperature.
- Students explain that the ground is warmed by the Sun, which then warms the air above it.

Incomplete or inaccurate ideas

- Students draw the surface temperature cooler than the air temperature.
- Students develop an explanation that indicates the air is heated from the Sun above, and not from the ground below.

Suggestions: Same as question 2.

4. The air temperature near the surface is different from the air temperature higher in the atmosphere. Explain how they are different and why this difference is necessary for a storm to form.

Performance Outcome: Explain how air temperature at the surface and high in the atmosphere create conditions/cause the formation of storms.

Indicators of progress

- Students mention air temperature conditions related to evaporation and condensation, identifying warmer temperatures near the surface as related to evaporation and cooler temperatures near the clouds as related to condensation, forming clouds and storms.
- If used after the Explore/before the Explain lessons, it's OK if students do not mention that warm air can evaporate more moisture. If this item is used after the Explain lesson, students may mention it here.

Incomplete or inaccurate ideas

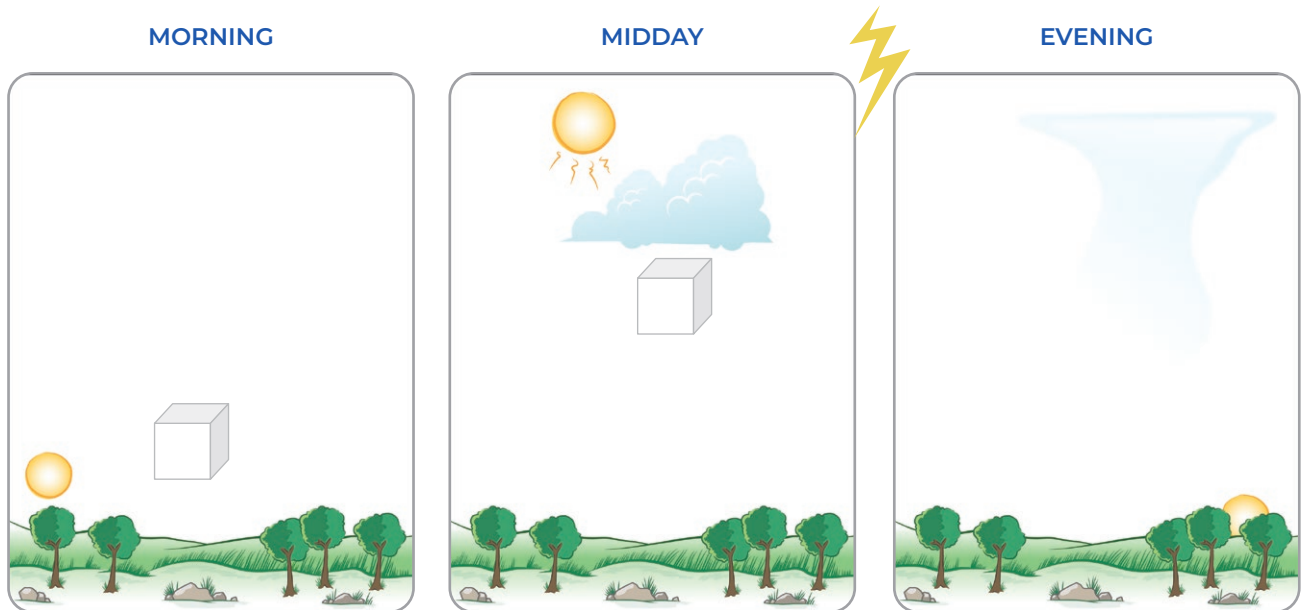
- Students do not connect temperature changes to evaporation or condensation.
- Students do not identify an accurate temperature gradient from the ground to the clouds.

Suggestions

- Revisit Lesson 3 data that students collected from the Virtual Ballooning interactive. Talk about what would be happening to water at the surface when it is warmed and what happens to water in cooler temperatures.
 - Flip the temperature gradient and ask students to explain changes if the alternative gradient were the case: If it was warm in clouds, what would happen to water? If it was cold at the surface, what would happen to water?
-

The pictures below show one location at three different times during one day: morning, midday, and evening. The day was sunny in the morning and then a thunderstorm formed around 3:00 p.m., which lasted an hour.

The boxes in the pictures represent a “pocket” of air that moves over time. In the morning, the air is near the ground. At midday (12:00 p.m.), the pocket of air has moved higher in the atmosphere. Answer the questions below to complete the model and to explain what it shows about the thunderstorm.



5. Draw a box to show where you think the pocket of air might be on the “Evening” diagram.

Performance Outcome: Develop a model to show how air rises and falls during a day.

Indicators of progress

- Box is drawn near the surface or lower than the middle box.

Incomplete or inaccurate ideas

- Box is drawn higher than or at the same level as the middle box.

Suggestions: Revisit the Mylar balloon demonstration (Lesson 5). Ask students to discuss what happened to warmed air when it reached cooler temperature higher in the atmosphere.

6. Explain why you put the box where you did.

Performance Outcome: Develop a model to show how air rises and falls during a day.

Indicators of progress

- Explanation includes ideas about cooling and/or sinking air. Students may also mention that vapor condensed from the air when the storm developed and/or talk about air particles getting closer together as it cools, causing it to sink back to the surface.

Incomplete or inaccurate ideas

- Students believe the air continues to rise after the storm.
- Students believe the air cools but stays at the same altitude.
- Students believe there is warm air above the cloud, and the cool air stays below the cloud (indicating the air is heated by the Sun directly and not heated from the ground below).

Suggestions: Revisit Mylar balloon demonstration and/or Air on the Move reading (Lesson 5).

7. Do you think the temperature and humidity of the air in the box is increasing, decreasing, or staying the same during the morning and midday (just before storm)? Circle your answers for each time in the table to the right.

	TEMPERATURE	HUMIDITY
MORNING	<p>Increasing</p> <p>Decreasing</p> <p>Staying the same</p>	<p>Increasing</p> <p>Decreasing</p> <p>Staying the same</p>
MIDDAY	<p>Increasing</p> <p>Decreasing</p> <p>Staying the same</p>	<p>Increasing</p> <p>Decreasing</p> <p>Staying the same</p>

Explain why you think the temperature and humidity would change like this during the morning and then midday, just before the isolated storm occurred.

Performance Outcome: Modify a model to describe the relationships between air temperature, humidity, time of day, and altitude.

Indicators of progress

- The answers to questions 3 and 4 are not completely clear cut, so look at student explanations here to determine whether they are on the right track.
- Morning—the stormy day pattern typically shows an increase in temperature and a decrease in humidity. Students may circle “increasing” humidity and explain that as soon as the Sun rises, the energy from the Sun warms the surface and evaporates water. This explanation would make increasing humidity a logical response. If students know more about how relative humidity is calculated in relation to temperature, they will understand why humidity decreases even if the amount of water increases.
- Midday—the stormy day pattern typically shows a quick increase in humidity and a slight drop in temperature during an isolated storm. Students should know that both variables need to rise to create conditions for storms, but students may also circle “decreasing” for temperature and provide a logical explanation for why this happens just before a storm.

Incomplete or inaccurate ideas

- Explanations that are counter to the stormy day pattern, for example, using the sunny pattern of increasing temperatures and decreasing humidity at midday leading up to the storm, show incomplete or inaccurate ideas.

Suggestions: Revisit the sunny day and stormy day graphs from Lesson 4. Have students reread their graph descriptions (steps 1-2), discuss their ideas, and write a caption to summarize the stormy day pattern graphs for morning, midday, and evening.

8. One student claims that the box would get larger between morning and midday, assuming that the molecules can't escape from the box. Do you agree or disagree? Explain your reasoning.

Performance Outcome: Students critique a model to describe the relationship between air temperature, particle arrangement, and time of day.

Indicators of progress

- Agree. As heat transfers to air particles, they move more and become spaced farther apart, which would make the box expand.
- If students have learned about particle motion, they may mention that thermal energy transfer causes the particles to gain kinetic energy.

Incomplete or inaccurate ideas

- Disagree. This explanation states that the only way for the box to expand is if there are more air molecules in it.

Suggestions: Revisit Mylar balloon demonstration and/or Air on the Move reading (Lesson 5).

9. Another student claims that if there was another box of air high in the atmosphere at midday, it would be colder than the air below so it would sink toward the ground. Do you agree or disagree? Explain your reasoning.

Performance Outcome: Students critique a model to describe how air moves due to temperature.

Indicators of progress

- Agree. Cooler air sinks while warm air rises during convection.

Incomplete or inaccurate ideas

- Disagree. Air higher in the atmosphere is always cooler so it doesn't sink. As students have learned that air is heated near the surface and is cooler higher in the troposphere, they may assume that cold air needs to be at higher altitude.

Suggestions: Revisit Mylar balloon demonstration and/or Air on the Move reading (Lesson 5).

10. Use what you learned about temperature and humidity patterns on a stormy day to explain why the storm happened in the afternoon instead of the morning.

Performance Outcome: Construct an explanation for the relationship between changes in air temperature and humidity over a day and the formation of storm clouds with altitude.

Indicators of progress

- Mention that there needs to be time for the air to warm and water to evaporate. There also needs to be time for moisture to move from the surface to higher in the atmosphere.

Incomplete or inaccurate ideas

- Responses focus only on temperature or only on humidity and do not mention that it is the combination of both that creates conditions for storm.
- Responses do not mention anything about the time, energy from the Sun, or indicate that they understand how energy from the Sun is causing processes like evaporation and convection.

Suggestions

- Ask students to think about why many days begin clear and by afternoon clouds form. Ask students to write step by step what needs to happen for clouds to form on a clear day.
 - Revisit the Consensus Model and Model Idea Tracker. See which Model Ideas would help students answer this question.
-

11. Describe how energy from the Sun helps to cause the storm.

Performance Outcome: Construct an explanation for why isolated storms depend on changes in sunlight.

Indicators of progress

- Students mention the role of sunlight or energy from the Sun in warming the surface and evaporating water at the surface. They may also mention that warmer air at the surface rises, bringing moisture or water vapor higher in the atmosphere.

Incomplete or inaccurate ideas

- Responses focus only on warm temperatures or only on evaporation and not the combination of both.
- Responses focus on sunlight warming the air directly.

Suggestions: Revisit students' Heating of Earth models and/or the Model Idea Tracker. Have students trace energy from the Sun to air molecule movement and convection.

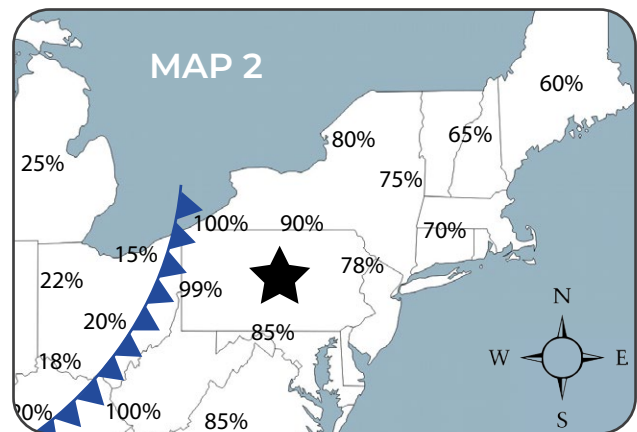
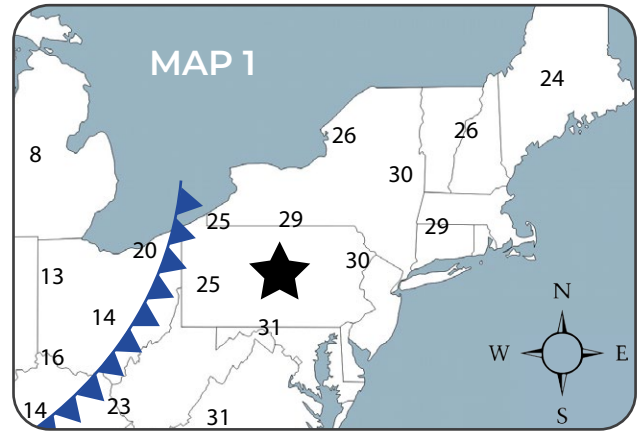
Learning Sequence 2 Assessment: A Front Headed Your Way

Map 1, to the right, shows maximum air temperatures (°C) across the northeastern United States on June 28, and Map 2 shows humidity (%).

Weather forecasts **for the next day** (June 29) in central Pennsylvania (shown on the maps with a star ★) predict the following:

▶ Temperatures will drop to 15-20°C, and storms are likely by the afternoon.

Answer the following questions to explain how weather forecasters used the data in these maps to decide that a storm is coming to central Pennsylvania.



1. The line with the triangles on each map shows the location of a cold front. Describe the temperature and humidity of the air on both sides of the front.

East of the front (to the right of the front on the map):

West of the front (to the left of the front on the map):

Performance Outcome: Use temperature and humidity data to describe the characteristics of air masses at a cold front.

Indicators of progress

- Students use the temperature and humidity data from the maps to identify that there is warm, moist air east of the front and cooler air with lower humidity west of the front.

Incomplete or inaccurate ideas

- Students focus on temperature differences only and do not recognize the importance of humidity in characterizing air masses.

Suggestions: If students do not perform well on this item, have them apply the color-coding strategies they used in Learning Sequence 2 to make sense of mapped data. For example, have students color warmer temperatures red and colder temperatures blue. They could also color-code the humidity map for humidity that is high and low.

2. Using what you know about the air on both sides of the front, describe how air is moving at the front.

Performance Outcome: Analyze temperature and humidity data to describe the interaction of air masses at a cold front.

Indicators of progress

- Students mention that warmer air on the right (east) side is pushed up by cooler air behind (to the west of) the cold front.

Incomplete or inaccurate ideas

- Students focus on wind and storms and the horizontal movement of air but do not recognize the vertical movement of air along the front where air masses interact.

Suggestions: Revisit the Warm Meets Cold demonstration (Lesson 9) with the density tank. Ask your students what is happening to the air right where the two air masses in the model meet.

3. Draw an **L** to show where you would expect to find the lowest air pressure on a map on the previous page and an **H** to show where you would expect to find the highest air pressure. Explain why you put the H and the L where you put them.

Performance Outcome: Analyze and interpret temperature and humidity data to identify regions of high and low pressure.

Indicators of progress

- Students place the L on the front symbol or at the northern end of the front. They place an H behind the front in the cooler air mass.
- Students explain that the area of low pressure is where air rises and the area of high pressure is located where air is relatively cooler and sinking.

Incomplete or inaccurate ideas

- Students may connect the low pressure only with storms and the high pressure only with blue skies and may not make the connection to rising or sinking air. This is not inaccurate but is incomplete.
- Students place the area of low pressure ahead of the front. Students may associate the colors used for the symbols with temperature and therefore draw a L with the warmer temperatures and a H with the cooler temperatures.

Suggestions: Reread about low and high pressure in Lesson 10. Also, revisit the Freedom High School air pressure data in Lesson 10 where students identified the lowest air pressure happening right at the front and the highest air pressure after the front.

4. Describe how you'd expect air pressure to change in central Pennsylvania (shown with a star ★ on the maps on the previous page) from June 28 to June 29 as the cold front moves through. Explain your reasoning.

Performance Outcome: Analyze and interpret temperature and humidity data to predict how air pressure would change over time.

Indicators of progress

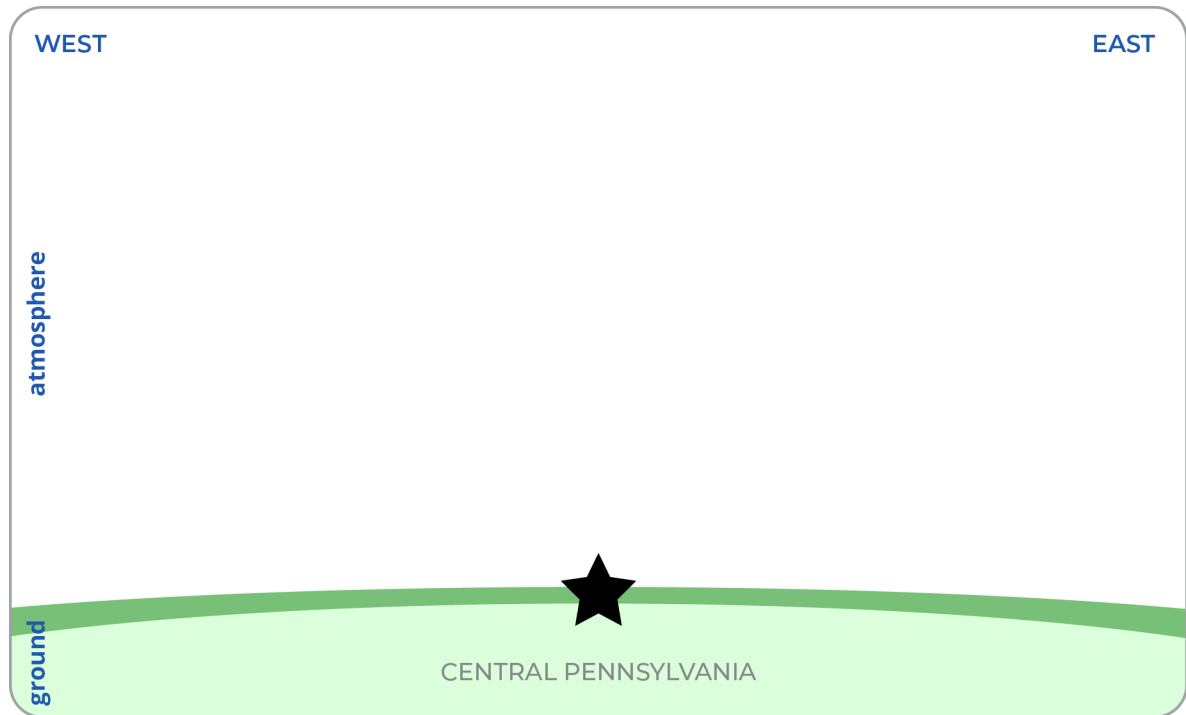
- Students identify that pressure will decrease from June 28 to June 29 as the front arrives.

Incomplete or inaccurate ideas

- Students may believe that pressure is already low on June 28 and will get higher on June 29. Remind students that June 28 is before the front and June 29 is during the front.

Suggestions: Reread about low and high pressure in Lesson 10. Also, revisit the Freedom High School air pressure data in Lesson 10 where students identified the lowest air pressure happening right at the front and the highest air pressure after the front.

5. Draw a cross-sectional model below to show how the air masses will interact along the cold front as it moves through central Pennsylvania (shown with a star ★) on June 29. Your model should:
- show the location of the cold front.
 - show the location of air masses (and note the temperature, humidity, and air pressure).
 - use arrows to show how air is moving.
 - indicate where a storm is likely to form.



6. How can the movement of the air shown in your cross-sectional model cause a storm? Explain your reasoning.

Performance Outcome for 5 & 6: Develop and use a model of a cold front to describe how cold air pushes warm air higher in the atmosphere, where it cools and water vapor condenses forming clouds.

Indicators of progress

- Students accurately place a cold front between a warm air mass and a cold air mass.
- Students identify the warm air mass as having higher humidity.
- Students identify the cold air mass as having lower humidity.

Students indicate upward movement of warm air as the cold air pushes under the warmer air, which results in clouds and precipitation forming at or near the front.

Incomplete or inaccurate ideas

- Students focus on temperature differences only and do not recognize the importance of humidity in characterizing air masses ahead of and behind the front.
- Students focus on wind and the horizontal movement of air but do not recognize the vertical movement of air as the warm air is lifted and the cold air pushes underneath.
- Students place the storms in the warmer air mass and not along the front.

Suggestions: Revisit the Warm Meets Cold demonstration (Lesson 9) with the density tank. Ask your students what is happening to the air right where the two air masses in the model meet.

7. Add an **H** to your cross-sectional model to show where air pressure would be highest and an **L** where air pressure would be lowest. How do these differences in air pressure cause the air to move?

Performance Outcome: Develop and use a model to describe how differences in air pressure based on air temperature cause higher pressure air to move toward and push lower pressure air.

Indicators of progress

- Students identify an area of high pressure behind the front with the cooler air mass.
- Students identify low pressure near the front where warm air is lifted and also near the surface.

- Students include in their model how air is moving from high pressure to low pressure. Students may indicate this using arrows or words.

Incomplete or inaccurate ideas

- Students indicate that the low pressure is ahead of the front and not along the front, which shows they associate low air pressure with the air mass.
- Students do not include a description or symbols depicting how air pressure influences the movement of air. Students may not understand the horizontal movement of air from high to low pressure.
- Students do not connect cooler temperature with sinking air or the flow of air away from areas of high pressure.

Suggestions: Reread about low and high pressure in Lesson 10. Also, revisit the Freedom High School air pressure data in Lesson 10 where students identified the lowest air pressure happening right at the front and the highest air pressure after the front.

8. Use your model and the temperature and humidity data on the maps to explain why it will likely rain in central Pennsylvania (star ★).

Performance Outcome: Analyze and interpret temperature and humidity data to support a claim about a cold front causing rain.

Indicators of progress

- Students use the temperature and humidity data from the maps to identify that there is warm, moist air on one side of the front, which is pushed up by cooler air behind the front. When the warm, rising air cools higher in the upper atmosphere, the water condenses to form clouds and storms. .

Incomplete or inaccurate ideas

- Students describe the cold front as being stormy without explanation of the upward lift of warm, moist air.
- Students associate the air behind the front with storms but not necessarily as contributing to the lift of the warm, moist air.
- Students do not mention that the rising, warm air eventually cools and water condenses from the air in the cooler temperatures higher in the atmosphere.

Suggestions: Revisit the Model Idea Tracker and the class Consensus Model from Learning Sequence 2. Discuss what is happening to the moisture where the two air masses interact. Discuss what would increase chances for more rain (higher humidity in the warm air mass) and what could decrease chances for rain (less humidity in the warm air mass).

9. In the table below, describe two similarities and two differences in how isolated storms and cold front storms form.

SIMILARITIES		DIFFERENCES	
1			
2			

Performance Outcome: Use knowledge about storms caused by cold fronts and isolated storms to make comparisons about their similarities and differences.

Indicators of progress

- Students identify similarities including the key role of warm, rising air and high humidity in storm formation.

- *Students identify differences including the length of time (hours for isolated storms versus days for cold front storms), the spatial scale (isolated storms occur in a single location while cold front storms occur along a regional front), and that cold fronts involve interacting air masses, while isolated storms happen within an air mass.*

Incomplete or inaccurate ideas

- *Any of the incomplete or inaccurate ideas previously mentioned could be included here.*
- *Students focus on temperature differences only and do not recognize the key role of humidity in storm formation*

Suggestions: Compare the class consensus models from Learning Sequences 1 and 2. Discuss which model ideas from the Model Idea Tracker pertain to both kinds of storms and which are exclusive to one or the other kind of storm.

10. What are some reasons that could explain why one air mass would have a higher temperature than another air mass? Explain each reason.
11. Think about what you know about air temperature around the Earth. Some areas are usually warmer than others. What causes some areas to be warmer than others?

Performance Outcome for 10 & 11 (working toward): Use knowledge of the relationship between sunlight and air temperature and that different places can have different amounts of sunlight and that air masses move from place to place to explain differences in temperature between two air masses.

Look for the following:

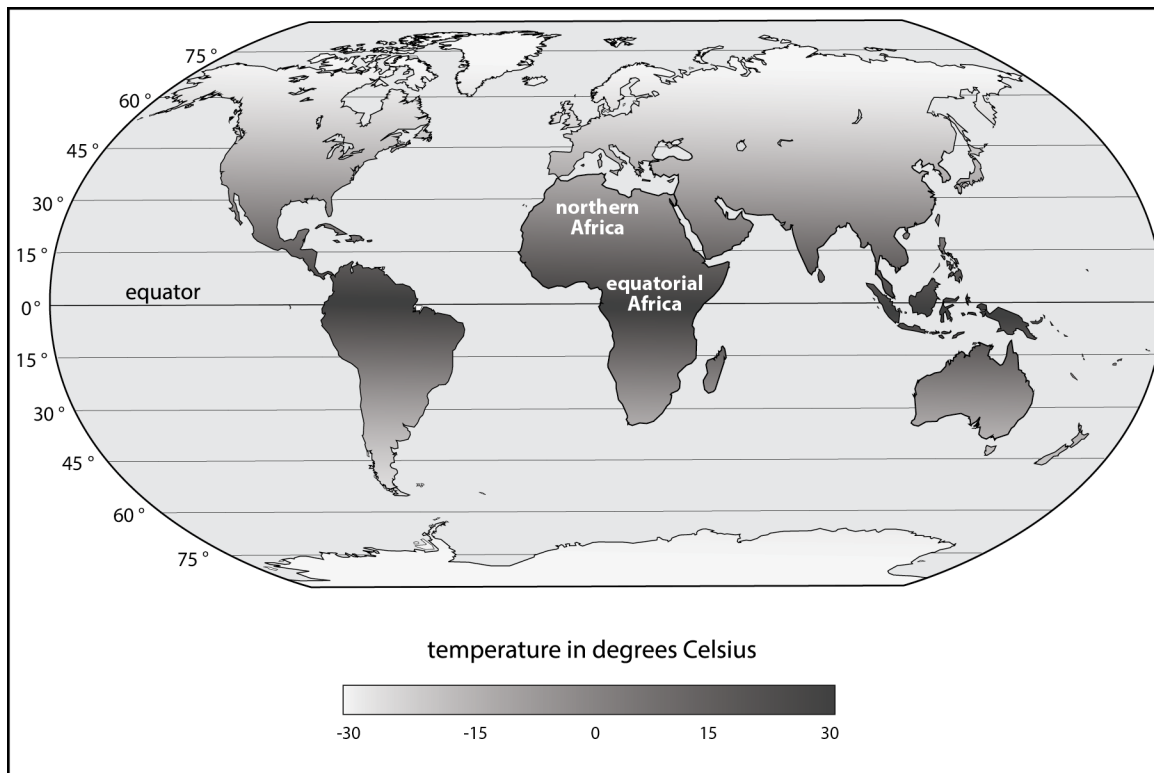
- *Students mention that the geographic location of the air mass matters.*
- *Students mention connections to sunlight and heating of Earth.*
- *Students mention latitude (warm places near the equator, cold places near the poles).*
- *Students mention that the season or time of year could be related.*

Suggestions: Use student ideas shared for questions 7 and 8 to inform your instruction during Learning Sequence 3.

Learning Sequence 3 Assessment: Worldwide Weather

Northern Africa is very dry and receives very little rainfall throughout the year. However, equatorial Africa has many storms, meaning a lot of rainfall. Examine the map below.

MAP 1. AVERAGE ANNUAL TEMPERATURE AROUND THE GLOBE.



1. Answer the questions to explain what causes the different temperature patterns in the map above.
 - a. Compare the average annual temperature in equatorial Africa to the average annual temperature in northern Africa.
 - b. Explain why the average annual temperatures are different in these two regions.

Performance Outcome: Develop an explanation for how uneven heating of Earth's surface causes different average annual temperatures in different regions of Africa.

Indicators of progress

- Question 1a: Students identify that annual temperatures near the equator are warmer on average than near 30°N.
- Question 1b: Students should indicate in their explanation that the uneven heating of Earth's surface causes temperatures to be warmer on average near the equator. This is because sunlight hits Earth near the equator straight on and is more concentrated or direct, leading to warmer temperatures. At higher latitudes, the same amount of sunlight is distributed over a larger area because of the curve of Earth, so light is more spread out and temperatures are cooler.

Incomplete or inaccurate ideas

- Students name "uneven heating of Earth's surface" in an explanation without a complete description of how or why that happens and how it causes cooler or warmer temperatures.
- Students explain that temperatures are warmer near the equator because those places are "closer to the Sun" and temperatures are cooler at higher latitudes because those places are "farther from the Sun".

Suggestions: Revisit Lesson 13: Step 1 if students struggle to see that temperatures are warmer around the equator and cooler at the poles. Lesson 13: Steps 2 and 3 will help students see that solar radiation is more concentrated at the equator and more spread out at higher latitudes, leading to the differences in average annual temperatures.

2. Draw on the cross-section below to show what is happening in the atmosphere above Africa. Focus on the tropics, which are between 30°N and 30°S latitude.
- Use arrows to show how air moves from the equator to the midlatitudes (from 0° to 30°N and also from 0° to 30°S).
 - Draw clouds where you would expect to find the most cloud cover in the atmosphere above Africa.
 - Add **H** for areas of high pressure and **L** for areas of low pressure.

Performance Outcome: Develop a model to show air movement between Earth's surface and the atmosphere

Indicators of progress

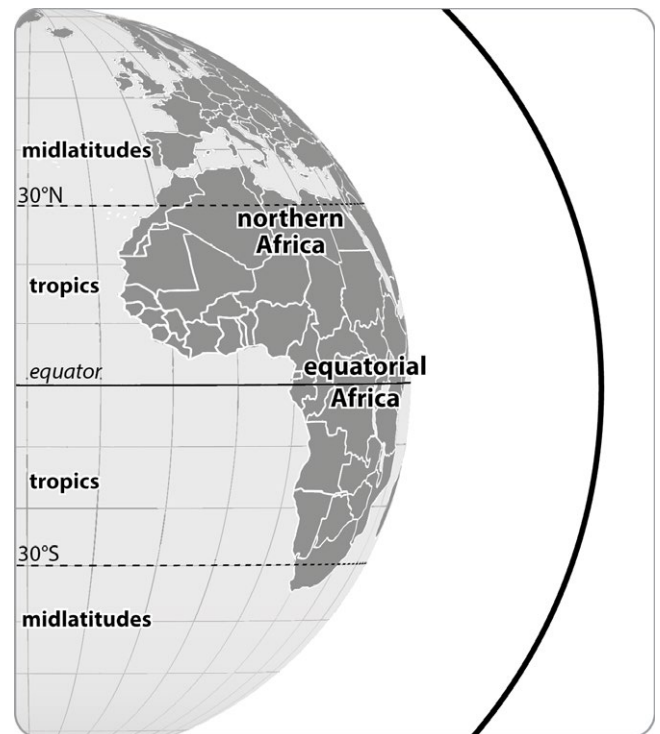
- Question 2a: Students draw circular arrows showing air rising near the equator, sinking near 30°N, and moving toward the equator across Earth's surface.
- Question 2b: Students add clouds to the area in the atmosphere above the equator. This indicates that they have transferred the cloud cover pattern from Map 1.
- Question 2c: Students mark areas of low pressure near the equator and areas of high pressure near 30°N.
- Students do not need to name this as "global air circulation" or "global convection cells".

Incomplete or inaccurate ideas

- Students draw some but not all of the following ideas: Air rises near the equator, air sinks near 30°N, and air moves across Earth's surface toward the equator. This indicates that they have developed some of the ideas about temperature, pressure, and air movement but have not put all the pieces together.

Suggestions: Revisit the convection tank demonstration from Lesson 14: Steps 2 and 3 or the diagram in Lesson 14: Step 5 to help students visualize how air moves in the tropics.

AIR MOVEMENT IN THE ATMOSPHERE ABOVE AFRICA



3. Explain how different average annual temperatures in the tropics and midlatitudes help cause the different patterns in air circulation in the two regions you drew in the cross-section above.

Performance Outcome: Use a model to explain how different average annual temperatures cause patterns of air movement across central and northern Africa.

Indicators of progress

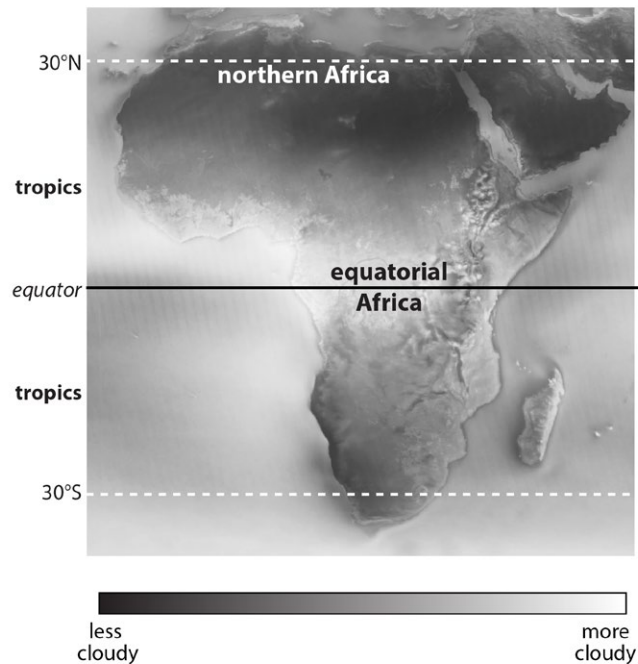
- Vertical air movement:** Students explain how warm air near the equator in tropical Africa means that air molecules are moving faster, are spread farther apart, and have lower pressure, causing them to rise. Cool air near 30°N means that air molecules are moving slower, are more dense, and have higher pressure, causing them to sink.
- Surface air movement:** Students explain how the differences in areas of high and low pressure cause the air to move from high to low pressure across Earth's surface toward the equator.

Incomplete or inaccurate ideas

- Students name convection without a complete description of how or why this is caused by temperature differences and results in movement of air.

Suggestions

- Revisit the Mylar balloon demonstration in Lesson 5: Step 1 and the reading in Lesson 5: Step 2 if students struggle with ideas about rising or sinking air, temperature, and pressure. Then help students connect these ideas on a global scale using the diagram in Lesson 13: Step 3 (temperature) and Lesson 14: Step 5 (pressure).
- If students struggle with why winds in the tropics move toward the equator, revisit the convection tank demonstration from Lesson 14: Steps 2 and 3.

MAP 2. PERCENT OF AVERAGE ANNUAL CLOUD COVER OVER AFRICA FROM 2002 TO 2015.

4. Examine map 2 above, which shows cloud cover.

Use what you know about how clouds form and the patterns in air circulation in the tropics to explain why there are fewer clouds in northern Africa.

Performance Outcome: Use knowledge of convection caused by uneven heating to explain why northern Africa has few clouds.

Indicators of progress

- Students connect cloud formation to warm, moist air rising in the area of low pressure at the equator and explain that these conditions are not present over northern Africa and/or students focus on relatively cooler, drier air sinking around 30°N, which does not create conditions for cloud formation.
- Students explain that air over tropical Africa cools as it rises, forms clouds, and releases moisture. By the time air has moved over northern Africa the moisture and the clouds are gone.

Incomplete or inaccurate ideas

- Students focus on cloud formation related to one variable only (e.g., it is hotter, so there are more clouds; there is more water at the equator, so there are more clouds). This shows they may understand part of the convection model but have not made connections to develop a complete model.
- Students may not connect sinking air at 30°N with drier air. This is an important piece of the model.

Suggestions: Revisit Lesson 5: Steps 2 and 3 to discuss how convection leads to cloud formation. Connect these ideas to convection at a global scale by returning to the diagram in Lesson 14: Step 5.

5. Storms in tropical Africa generally do not move directly north from the equator toward northern Africa. Draw on the image below to explain the movement of storms in this part of the world.
- At 30°N, winds spread out across Earth's surface. Draw the direction that winds would travel north and south of 30°N if the Earth was not spinning.
 - Use a different color to draw how winds actually curve north and south of 30°N due to the Coriolis effect.
 - Use what you know about the direction of winds to explain why storms in tropical Africa do not equatorial move directly north from the equator toward northern Africa.

Performance Outcome: Develop an explanation for how atmospheric circulation in the tropics and midlatitudes and the Coriolis effect cause patterns of surface winds across northern and tropical Africa.

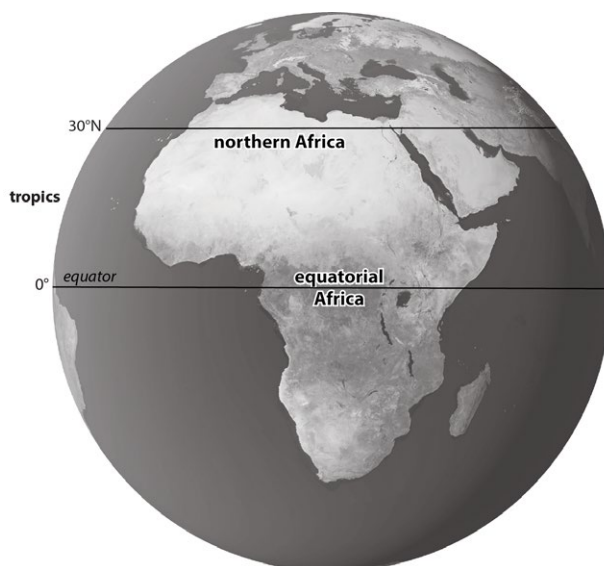
Indicators of progress

- Question 5a: Students add arrows to the image showing winds moving south from 30°N toward the equator and north from 30°N toward the poles with no deflection.
- Question 5b: If students draw any curved arrows, that shows they understand that the Coriolis effect causes winds to curve. If students curve arrows to the right above 30°N and to the left below 30°N (from a bird's eye view) this shows they understand the direction winds curve due to the Coriolis effect.
- Question 5c: Students should indicate in their explanation that storms do not move from the equator to 30°N because (1) convection causes air to move from 30°N toward the equator and (2) the Coriolis effect resulting from Earth's rotation causes those winds to curve moving from east to west near the equator. The combination of the two is an important indicator of progress in both their explanation and drawing.

Incomplete or inaccurate ideas

- Students draw or explain air moving only north-south or only east-west. This indicates they are not thinking about the combination of convection and the Coriolis effect.
- If students don't show winds curving to the right, this indicates that they don't understand the direction winds curve due to the Coriolis effect.
- Students name convection or the Coriolis effect in their explanation without a complete description of how or why either results in movement of air. For the Coriolis effect, a connection to Earth's spin is sufficient. For convection, students should explain unequal heating of Earth's surface at different latitudes.


Suggestions: Revisit Lesson 5: Steps 2 and 3 to discuss how convection leads to cloud formation. Connect these ideas to convection at a global scale by returning to the diagram in Lesson 14: Step 5.



**DIRECTION OF WIND IN
NORTHERN AND EQUATORIAL
AFRICA**

Question 1 Rubric

Rubric Measures: Students explain what causes patterns of weather movement in the tropics and midlatitudes and support their explanations using ideas about the Coriolis effect.

PERFORMANCE EXPECTATION	ALIGNMENT TO NGSS DIMENSIONS 	PERFORMANCE OUTCOMES	ALIGNMENT TO PROMPT/CRITERIA IN PERFORMANCE ASSESSMENT
<p>MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates:</p>	<p><i>SEP – Constructing Explanations:</i> Apply scientific ideas, principles and/or evidence to construct, revise, and/ or use an explanation for real-world phenomena, examples, or events.</p> <p><i>DCI – ESS2.D:</i> Weather and climate are influenced by the interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns.</p> <p><i>CCC – Cause and Effect:</i> Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.</p>	<p>Develop an explanation for how the Coriolis effect causes patterns of air mass movement in the tropics and midlatitudes.</p>	<p>Weather forecasters know there is a direction weather usually follows as air masses move in the midlatitudes and tropics. Answer the next two questions to explain why forecasters often predict that weather will move in the direction of the arrows shown on the globe below.</p> <p>1. Why is the arrow showing wind direction curving to the east at point A? Why is the arrow curving to the west at point B?</p>

Correct Answer

Air that would be moving south toward the equator is curved to the west, and air that would be moving north toward the pole is curved to the east because of the Coriolis effect. The wind is curved because of Earth's rotation.

Question 1 Rubric | **Rubric Measures:** Students explain what causes patterns of weather movement in the tropics and midlatitudes and support their explanations using ideas about the Coriolis effect.


	Emerging ¹ -1	Developing-2	Proficient-3
PERFORMANCE	Explanation uses irrelevant or minimal science ideas about the Coriolis effect as a cause of air mass movement AND reasoning connecting the cause/s to the phenomenon is irrelevant or missing .	Explanation uses partially accurate and relevant science ideas about the Coriolis effect as a cause of air mass movement BUT reasoning connecting the cause/s to the phenomenon is irrelevant or missing .	Explanation uses accurate and relevant science ideas about the Coriolis effect as a cause of air mass movement AND reasoning connecting the cause/s to the phenomenon is present .
LOOK FOR	<ul style="list-style-type: none"> Describes some aspects related to the Coriolis effect. No reasoning or reasoning is irrelevant. 	<ul style="list-style-type: none"> Mentions the Coriolis effect but not what it means. No reasoning or reasoning does not link how the cause leads to observed east-west patterns in air mass movement. Mentions keywords (Coriolis effect) but with no real explanation. 	<ul style="list-style-type: none"> Describes the Coriolis effect. Describes Earth's rotation as the cause of observed patterns in air mass movement. Does not necessarily need to use the vocabulary "Coriolis effect" if the description includes a discussion of Earth's rotation.
SAMPLE RESPONSE	<i>The earth moves this way because clouds move this way.</i>	<i>Weather moves this way because of the Coriolis effect.</i>	<p><i>Weather usually moves from west to east or east to west because of the rotation of the Earth.</i></p> <p><i>In the tropics, the weather moves to the west, and in the midlatitudes, weather moves to the east. This happens because the earth is spinning, which causes air to curve east to west or west to east. (Note: Students may mention that this west-east movement happens in the Northern Hemisphere.)</i></p>

¹ If the student provides no assessable evidence (e.g., "I don't know" or leaves the answer blank), then that student response cannot be evaluated using the rubric.

² NGSS assessment boundary for this PE states: "Assessment does not include the dynamics of the Coriolis effect". A level 3 response on this rubric, therefore, does not expect students to reason further about the Coriolis effect than it is due to Earth's rotation.

Question 2 Rubric

Rubric Measures: Students explain what causes patterns of weather movement in the tropics and midlatitudes and support their explanation using ideas about global convection.

PERFORMANCE EXPECTATION	ALIGNMENT TO NGSS DIMENSIONS 	PERFORMANCE OUTCOMES	ALIGNMENT TO PROMPT/CRITERIA IN PERFORMANCE ASSESSMENT
<p>MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.</p>	<p><i>SEP – Constructing Explanations:</i> Apply scientific ideas, principles and/or evidence to construct, revise, and/or use an explanation for real-world phenomena, examples, or events.</p> <p><i>DCI – ESS2.D:</i> Weather and climate are influenced by the interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns.</p> <p><i>CCC:</i> Cause and effect relationships may be used to predict phenomena in natural or designed systems.</p>	<p>Develop an explanation for how global convection causes patterns of air mass movement in the tropics and midlatitudes.</p>	<p>2. If the Earth didn't spin, what direction would the air in the region of A move? What direction would the air in the region of B move?</p>

Correct Answer

If the Earth didn't spin, then the Coriolis effect would not curve global winds. Air at point A would move north, and air at point B would move south because of global convection. Global convection happens because the planet is heated more at the equator than anywhere else, so warm air rises there.


Question 2 Rubric | **Rubric Measures:** Students explain what causes patterns of weather movement in the tropics and midlatitudes and support their explanation using ideas about global convection.

	Emerging ³ -1	Developing-2	Approaching Proficiency-3	Excelling-4
PERFORMANCE	Explanation uses irrelevant or minimal science ideas about global convection as a cause of air mass movement AND reasoning connecting the cause/s to the phenomenon is irrelevant or missing .	Explanation uses partially accurate and relevant science ideas about global convection as a cause of air mass movement BUT reasoning connecting the cause/s to the phenomenon is irrelevant or missing .	Explanation uses accurate and relevant science ideas about global convection as a cause of air mass movement BUT reasoning connecting the cause/s to the phenomenon is vague or general and doesn't describe how the cause explains patterns of air mass movement.	Explanation uses accurate and relevant science ideas about global convection as a cause of air mass movement AND reasoning connecting the cause to the phenomenon describes how the cause explains patterns of air mass movement.
LOOK FOR	<ul style="list-style-type: none"> Describes some aspects related to convection. No reasoning or reasoning is irrelevant. 	<ul style="list-style-type: none"> Describes aspects of convection (air circulation, areas of high and low pressure, warm temp at equator and cool temp at 30°N). No reasoning or reasoning does not link how the cause leads to observed north-south patterns in air mass movement (i.e., mentions keywords such as convection, high/low pressure, uneven heating but offers no explanation). 	<ul style="list-style-type: none"> Describes aspects of convection (air circulation, areas of high and low pressure, warm temp at equator and cool temp at 30°N). Vague, but present, reasoning linking how convection leads to observed north-south patterns in air mass movement. 	<ul style="list-style-type: none"> Describes convection (air circulation, areas of high and low pressure, warm temp at equator and cool temp at 30°N). Reasoning explains how or why convection results in observed north-south patterns in air mass movement.
SAMPLE RESPONSE	<i>If the Earth didn't spin, then the clouds wouldn't move the way that they do.</i>	<p><i>If the Earth didn't spin, then weather would move because of the differences in low and high pressure.</i></p> <p><i>Because of the sunlight directly hitting the equator and indirectly hitting the midlatitudes.</i></p>	<i>If the Earth didn't spin, then warm air would rise from the equator, cool air from the pole moves downward to take the warm air's place.</i>	<i>If the Earth didn't spin, then the Coriolis effect would not curve global winds. Air at point A would move north, and air at point B would move south because of global convection. Global convection happens because the planet is heated more at the equator than anywhere else.</i>

³ If the student provides no assessable evidence (e.g., "I don't know" or leaves the answer blank), then that student response cannot be evaluated using the rubric.

Question 3 Rubric

Rubric Measures: Students analyze and interpret the pattern in air pressure data for air masses at a front to determine upward and downward movement.

PERFORMANCE EXPECTATION	ALIGNMENT TO NGSS DIMENSIONS 	PERFORMANCE OUTCOMES	ALIGNMENT TO PROMPT/CRITERIA IN PERFORMANCE ASSESSMENT
<p>MS-ESS2-5: Collect data to provide evidence for how the motions and complex interactions of air masses result in changes in weather conditions.</p>	<p><i>SEP:</i> Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships.</p> <p><i>DCI:</i> Air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.</p> <p><i>CCC:</i> Students use graphs and charts to identify patterns in data.</p>	<p>Analyze and interpret pattern in air pressure data to explain why air moves vertically in areas of high and low pressure.</p>	<p>A school in Nebraska is planning a graduation party for a day in May. One day before the party, weather forecasters warned:</p> <p><i>Even though it is warm and sunny now, a cold front will soon move into Nebraska. Tomorrow the weather will become cool and rainy.</i></p> <p>The weather forecasters used air pressure data (measured in millibars; shown on the map below) to predict more precisely how the front will move.</p> <p>3. Use the air pressure data and cold front shown in the map to describe how air is moving at location A. Explain why it moves this way. Now describe how the air is moving at location B. Explain why it is moving this way.</p>


Correct Answer

Location A has lower air pressure than other areas on the map, and it's located at the cold front, so air will be rising. Low pressure air rises because it is warmer and less dense than the air around it. Location B on the map shows higher air pressure, and it's between the area with the highest pressure (to the west) and the cold front with lower pressure (to the east), so the air will be moving from west to east. Also, because it's higher pressure, air will be sinking because the air is cooler and more dense than the air around it.

Question 3 Rubric | **Rubric Measures:** Students analyze and interpret the pattern in air pressure data for air masses at a front to determine upward and downward movement.

	Emerging -1	Developing-2	Approaching Proficiency-3	Excelling-4
PERFORMANCE	<p>Does not interpret the significance of the pattern, or makes inaccurate inferences about air moving up and down in areas of high and low pressure AND does not support inferences.</p>	<p>Interpretation makes some accurate and inaccurate inferences about air moving up and down in areas of high and low pressure BUT supports them with inaccurate or irrelevant information or does not support inferences.</p>	<p>Interpretation makes accurate inferences about air moving up and down in areas of high and low pressure AND vaguely supports interpretation with reasoning about why air moves this way in those locations.</p>	<p>Interpretation makes accurate inferences about air moving up and down in areas of high and low pressure AND explicitly supports interpretation with reasoning about why air moves this way in those locations.</p>
LOOK FOR	<ul style="list-style-type: none"> • Air moves down at location A. • Air moves up at location B. • Does not explain the upward or downward movement. • No reasoning provided or reasoning is irrelevant. 	<ul style="list-style-type: none"> • Correctly identifies that air moves up and down because of pressure, but does not clearly connect up and down to high or low pressure. • Correctly identifies up at location A and down at location B, but applies no reasoning or reasoning uses inaccurate information. 	<ul style="list-style-type: none"> • Identifies that high pressure air (location B) is associated with sinking air, and low pressure air (location A) is associated with rising air. • Provides very little explanation of how they know this. 	<ul style="list-style-type: none"> • Identifies that high pressure (location B) is associated with sinking air and low pressure (location A) is associated with rising air. • Reasoning explains something about the space between air molecules, density of air, or movement of molecules (e.g., high-pressure molecules are closer together, moving less, and sinking; low-pressure air molecules are spread apart, moving more, and rising) Note: Reasoning does not need to include references to air molecules to be excelling.
SAMPLE RESPONSE	<p><i>Air would be blowing a lot in location A.</i></p> <p><i>Location A would have air pushing down on it.</i></p>	<p><i>Air rises in areas of low pressure, so that's why it's windy.</i></p>	<p><i>In areas with high pressure, air flows from the atmosphere to the surface (down), and areas of low pressure have rising air.</i></p>	<p><i>Areas of high pressure are usually colder and particles are closer together and sinking. Areas of low pressure usually have more rising air and particles are spread apart.</i></p>

Question 4 Rubric | **Rubric Measures:** Student uses analysis of pressure data to explain the direction of movement of air masses (across the surface).

PERFORMANCE EXPECTATION	ALIGNMENT TO NGSS DIMENSIONS 	PERFORMANCE OUTCOMES	ALIGNMENT TO PROMPT/CRITERIA IN PERFORMANCE ASSESSMENT
<p>MS-ESS2-5: Collect data to provide evidence for how the motions and complex interactions of air masses result in changes in weather conditions.</p>	<p><i>SEP:</i> Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships.</p> <p><i>DCI:</i> Air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.</p> <p><i>CCC:</i> Cause and effect relationships may be used to predict phenomena in natural or designed systems.</p>	<p>Use air pressure data to explain why air masses move across the surface from high to low pressure.</p>	<p>4. Use the air pressure data and your knowledge about how air is moving at locations A and B to explain why weather forecasters predict that the front will likely move to Nebraska.</p>

Correct Answer | Students indicate that air masses move from areas of high pressure to low pressure. Air pushes away from higher pressure areas at the ground surface and moves toward areas of lower pressure. That is why the overall movement of the cold front is going from high to low pressure (west to east). Students need to use the vertical movement of air (Question 3) to help them explain the movement from west to east (horizontal movement) across the surface. Students do not need to explain clockwise or counterclockwise rotation (Coriolis effect) or prevailing winds as part of their explanation.


Question 4 Rubric | **Rubric Measures:** Student uses analysis of pressure data to explain the direction of movement of air masses (across the surface).

	Emerging ⁴ -1	Developing-2	Approaching Proficiency-3	Excelling-4
PERFORMANCE	Uses irrelevant or inaccurate information to predict direction of motion and supports explanation with inaccurate or irrelevant information or does not support explanation.	Explanation is partially supported with an accurate interpretation of data but provides either an inaccurate or irrelevant explanation about how air masses of different pressure interact or no explanation at all.	Explanation is supported with an accurate interpretation of the data BUT an incomplete or vague explanation about how masses of different pressure interact.	Explanation is fully supported using an accurate interpretation of the data and a complete explanation about how air masses of different pressure interact.
LOOK FOR	<ul style="list-style-type: none"> Does not identify high pressure sinking and low pressure rising. Does not identify high pressure push and low pressure pulling or rising. 	<ul style="list-style-type: none"> Description of higher pressure pushing the lower pressure mass east (toward Nebraska) with no explanation. Description of prevailing winds as the mechanism of movement, not pressure differences. Description of up and down movement of air but not connected to the east-west movement. 	<ul style="list-style-type: none"> Description of a higher pressure air mass moving east toward a lower pressure air mass with vague reference to high pressure pushing down or out and low pressure rising up or away. 	<ul style="list-style-type: none"> Description of a higher pressure air mass moving east toward a lower pressure air mass. Explanation includes a mechanism for motion, such as when two air masses interact the higher pressure air moves below the lower pressure air, causing lower pressure air to move upward and causing higher pressure air to move in the direction of the lower pressure air.
SAMPLE RESPONSE	<i>The front will probably move to Nebraska because wind blows west to east.</i>	<i>Higher pressure will move to lower pressure, which makes it move to Nebraska.</i>	<i>High pressure air moves downward and spreads outward, and low pressure air moves upward, so nearby air rushes to fill the space.</i>	<i>High pressure air pushes into low pressure air that is rising and pushes low pressure air upward. The high pressure air is spreading out pushing toward low pressure. That is why the air masses move to low pressure.</i>

⁴ If the student provides no assessable evidence (e.g., "I don't know" or leaves the answer blank), then that student response cannot be evaluated using the rubric.

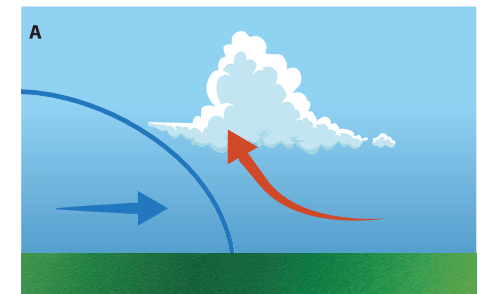
Question 5 Rubric

Rubric Measures: Students develop a model to show how the cold air causes the warmer air to move upward when two air masses interact at a cold front.

PERFORMANCE EXPECTATION	ALIGNMENT TO NGSS DIMENSIONS 	PERFORMANCE OUTCOMES	ALIGNMENT TO PROMPT/CRITERIA IN PERFORMANCE ASSESSMENT
<p>MS-ESS2-5: Collect data to provide evidence for how the motions and complex interactions of air masses result in changes in weather conditions.</p>	<p><i>SEP:</i> Develop and/or use models to describe and/or predict phenomena.</p> <p><i>DCI:</i> Air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.</p>	<p>Develop a model to show how warm and cold air masses interact along a cold front.</p>	<p>5. Think about the temperature of the air masses that make up a cold front and the air pressure data from the map on the previous page. When the cold front arrives in Nebraska, what will happen to the warm air that is there now? Draw and label a cross-sectional model in the box below to show how the air masses will interact.</p> <p>Your model should show:</p> <ul style="list-style-type: none"> • the warm air mass • the cold air mass • the location of the cold front • the direction that the cold front is moving • what causes the cold front to move this way

Correct Answer

- Students accurately place a cold front between a warm air mass and a cold air mass.
- Students indicate (with an arrow or some other symbol) the cold air is pushing into the warm air.
- Students indicate (with an arrow or some other symbol) an upward lift of the warm air mass as the cold air pushes under the warmer air.
- Students indicate that the front is moving from west to east, toward Nebraska.
- Students may label the “cause” or mechanism for why the air masses move this way (e.g., density differences, pressure differences).




Question 5 Rubric | **Rubric Measures:** Students develop a model to show how the cold air causes the warmer air to move upward when two air masses interact at a cold front.

	Emerging ⁵ -1	Developing-2	Approaching Proficiency-3	Excelling-4
PERFORMANCE	Model shows an inaccurate or irrelevant prediction about where the warm air mass will move AND how the air masses interact OR an accurate prediction of direction without any explanation or interaction.	Model shows a partially accurate prediction about where the warm air mass will move AND how the air masses interact.	Model shows an accurate prediction of where the warm air mass will move and generally describes how the air masses interact.	Model shows an accurate and clear prediction of where the warm air mass will move AND how it interacts with the cold air mass.
LOOK FOR	<ul style="list-style-type: none"> Incorrectly describes the direction of the movement of both air masses or does not describe the movement of either. Gets the direction correct, but does not include an accurate mechanism to describe the movement. 	<ul style="list-style-type: none"> Incorrectly describes the direction of the movement of one air mass or does not describe the movement of both air masses. Does not include an accurate mechanism for movement of warm air or the mechanism is really vague. 	<ul style="list-style-type: none"> Model shows the two air masses and upward movement of warm air. Either the model or the description doesn't clearly include a mechanism (e.g., very limited ideas that cold air is pushing the warm air upward). 	<ul style="list-style-type: none"> Shows the cold air pushing into the warm air as it moves east. Includes a mechanism (e.g., the warm air moves upward over the cold air).
SAMPLE RESPONSE	<i>My model shows the cold front colliding with the warm air and the directions they are going. (Model does not show any consistency in air flow or cold air rising.)</i>	<i>My model shows that when cold and warm air meet at a cold front, the cold front pushes the warm air away. (Model does not show the warm air going over the cold air.)</i>	<i>My model shows that when cold and warm air meet at a cold front, the cold air goes under the warm air and pushes it up.</i>	<i>My model shows two air masses; one being cool and the other being warm. The warm air will rise because it is low pressure, and the cool air will sink because it is high pressure.</i>

⁵ If the student provides no assessable evidence (e.g., "I don't know" or leaves the answer blank), then that student response cannot be evaluated using the rubric.

Question 6 Rubric

Rubric Measures: Students explain the upward lift of warm air with respect to pressure or density differences between interacting air masses.

PERFORMANCE EXPECTATION	ALIGNMENT TO NGSS DIMENSIONS 	PERFORMANCE OUTCOMES	ALIGNMENT TO PROMPT/CRITERIA IN PERFORMANCE ASSESSMENT
<p>MS-ESS2-5: Collect data to provide evidence for how the motions and complex interactions of air masses result in changes in weather conditions.</p>	<p><i>SEP:</i> Develop and/or use models to describe and/or predict phenomena.</p> <p><i>DCI:</i> Air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.</p> <p><i>CCC:</i> Cause and effect relationships may be used to predict phenomena in natural or designed systems.</p>	<p>Use a model to explain why warm air rises over cold air along a cold front.</p>	<p>6. Explain why the warm air and cold air will move the way you showed in your model</p>

Correct Answer


- Students explain the upward lift as the cold air pushes under the warmer air. Students may explain this in terms of air pressure or air density depending on what you emphasized in your instruction.
- Students should indicate the cold air has higher pressure or is more dense than warm air and is pushing into the warm air with lower pressure. They should also say that the warm air is less dense, with lower pressure, and is rising away from the surface.

Question 6 Rubric | **Rubric Measures:** Students explain the upward lift of warm air with respect to pressure or density differences between interacting air masses.

	Emerging ⁶ -1	Developing-2	Approaching Proficiency-3	Excelling-4
PERFORMANCE	Explanation uses irrelevant, minimal, or inaccurate science ideas about the upward lift of warm air AND reasoning connecting the cause/s to the phenomenon is irrelevant or missing .	Explanation uses partially accurate and relevant science ideas about the upward lift of warm air OR pressure differences between two air masses BUT reasoning connecting the cause/s to the phenomenon is irrelevant or missing .	Explanation uses accurate and relevant science ideas about the upward lift of warm air OR pressure differences between two air masses. Reasoning connecting the cause/s to the phenomenon is vague or general in explaining patterns in how warm and cold air move when they interact due to temperature or pressure differences.	Explanation uses accurate and relevant science ideas about the upward lift of warm air OR pressure differences between two air masses AND reasoning connects the cause/s to the phenomenon in a clear and explicit way.
LOOK FOR	<ul style="list-style-type: none"> Cold air rising, warm air sinking OR movement from low to high pressure. Focusing on precipitation, or the location, such as Nebraska. 	<ul style="list-style-type: none"> General reference to warm air rising and cold air sinking with no explanation about why this pattern happens. 	<ul style="list-style-type: none"> Explanation is present, but it is not clear. May reference pressure, density, or molecular movement in the explanation, but the description of the mechanism is limited. 	<ul style="list-style-type: none"> Explanation is present, clear, and accurate. References pressure or density to describe the motion. Note: May reference molecular movement in the explanation.
SAMPLE RESPONSE	<p><i>Because of humidity and how the wind moves by the precipitation.</i></p> <p><i>It goes that way because warm air pushes the cold air.</i></p> <p><i>The air will mix to make a tornado.</i></p>	<p><i>Because warm air rises and cold air sinks.</i></p> <p><i>Because warm air rises and cold air pushes warm air up.</i></p>	<p><i>The warm air goes above because the pressure pushes it.</i></p>	<p><i>Warm air is less dense, and it will rise above cold air.</i></p> <p><i>The air will move this way because cold air has higher pressure and it sinks, while warm air moves up because of the low pressure.</i></p>

⁶ If the student provides no assessable evidence (e.g., "I don't know" or leaves the answer blank), then that student response cannot be evaluated using the rubric.

Question 7 Rubric | **Rubric Measures:** Students explain the upward lift of relatively more humid air into cooler altitudes forming clouds and storms.

PERFORMANCE EXPECTATION	ALIGNMENT TO NGSS DIMENSIONS 	PERFORMANCE OUTCOMES	ALIGNMENT TO PROMPT/CRITERIA IN PERFORMANCE ASSESSMENT
<p>MS-ESS2-5: Collect data to provide evidence for how the motions and complex interactions of air masses result in changes in weather conditions.</p>	<p><i>SEP:</i> Develop and/or use models to describe and/or predict phenomena.</p> <p><i>DCI:</i> Air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.</p> <p><i>CCC:</i> Cause and effect relationships may be used to predict phenomena in natural or designed systems.</p>	<p>Use a model to explain why a cold front (where warm and cold air masses interact) often causes rain.</p>	<p>7. Before the cold front moved into Nebraska, students noticed it felt very muggy or humid. Use your model to explain why it will probably rain in Nebraska during the graduation party.</p>

Correct Answer | Students accurately describe the warm air as more humid and the upward lift of this air into cooler temperatures at higher altitudes, resulting in condensation and then precipitation, which forms near/at the front where the warm, moist air is lifted.


Question 7 Rubric | **Rubric Measures:** Students explain the upward lift of relatively more humid air into cooler altitudes forming clouds and storms.

	Emerging ⁷ -1	Developing-2	Approaching Proficiency-3	Excelling-4
PERFORMANCE	Explanation uses irrelevant, minimal, or inaccurate science ideas about the upward lift of warm, moist air AND reasoning connecting the cause/s to the phenomenon (rain event) is irrelevant or missing .	Explanation uses partially accurate and relevant science ideas about the upward lift of warm, moist air BUT reasoning connecting the cause/s to the phenomenon is irrelevant or missing .	Explanation uses accurate and relevant science ideas about the upward lift of warm, moist air. Reasoning connecting the cause/s to the phenomenon is vague or general (e.g., a general description of water cycling).	Explanation uses accurate and relevant science ideas about the upward lift of warm, moist air AND reasoning connects the cause/s to the phenomenon, explaining the cool temperature at higher altitudes resulting in condensation of water.
LOOK FOR	<ul style="list-style-type: none"> • Applies incorrect science ideas like cold air moving up, warm air staying low. • East-west movement and not the vertical lift of warm air. • Cold air bringing moisture with it. • Collision of air, tornados. 	<ul style="list-style-type: none"> • General connection of warm, rising air to clouds or storms. • Mix of correct and incorrect ideas (e.g., warm air going up causing evaporation). 	<ul style="list-style-type: none"> • Describes an accurate water cycle story, but it's not necessarily connected to the frontal phenomena. • Provides little to no connection to cooler temperatures higher in the atmosphere. 	<ul style="list-style-type: none"> • Clearly links upward movement of moisture condensing with cooler temperatures higher in the atmosphere. • Reasoning is clear and detailed and connects the upward movement of warm, moist air to the phenomenon of rain at a frontal boundary.
SAMPLE RESPONSE	<p><i>Since the front is going over Nebraska, it will most likely rain. It will also be cold because the warm air will bring the warm air with it to fuel the storm.</i></p> <p><i>When a cold front arrives, it usually brings rain with it.</i></p>	<p><i>Well, if it's hot there, before the cold front gets there, the sun will make the water evaporate. When the cold front gets there, it'll drop all the water.</i></p> <p><i>It will probably rain because the cold air will push the warm air up, causing evaporation and condensation. Then it will rain.</i></p>	<p><i>Water droplets evaporate and rise into the air then mix with the warm air to make clouds (condensation). The droplets then merge with dust particles and become heavier so the clouds have to release them as rain, (or snow, sleet, or hail) in precipitation.</i></p>	<p><i>In my model, the warm air is being pushed up. Since it is colder at higher altitudes, the water vapor in the warm air mass would condense and form a cloud. If there is too much moisture, it will precipitate.</i></p>

⁷ If the student provides no assessable evidence (e.g., "I don't know" or leaves the answer blank), then that student response cannot be evaluated using the rubric.

Question 8 Rubric

Rubric Measures: Students identify that surface temperatures are warmer than the air temperatures above the surface, and they explain this concept using ideas about heating of the surface by the Sun, followed by heating the air above the surface.

PERFORMANCE EXPECTATION	ALIGNMENT TO NGSS DIMENSIONS 	PERFORMANCE OUTCOMES	ALIGNMENT TO PROMPT/CRITERIA IN PERFORMANCE ASSESSMENT
<p>ESS2-4: Develop a model to describe the cycling of water through Earth's systems driven by energy from the Sun and the force of gravity.</p>	<p><i>SEP:</i> Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and non-linear relationships.</p> <p><i>DCI:</i> Global movement of water and its changes in form are propelled by sunlight and gravity.</p> <p><i>CCC:</i> Patterns in rates of change and other numerical relationships can provide information about natural and human-designed systems.</p>	<p>Use knowledge of daily patterns in surface temperature and their relationship to air temperature to draw a graph of changes in surface temperature over a day.</p>	<p>8. A school in Des Moines, Iowa has a similar problem. On graduation day there was a thunderstorm around 4:00 p.m. that stopped after about an hour. Use the air temperature and humidity data in the graphs below to analyze the storm.</p> <p>8a. Think about how air temperature and surface temperature are different. Scientists reported that ground surface temperature at 7:00 am was 23°C. Draw a new line on the air temperature graph above to show how the surface temperature changes during the day.</p> <p>8b. Explain why ground surface temperature would follow the line that you drew.</p>

Correct Answer


- Students correctly draw the surface temperature data mirroring (at least mostly) the air temperature data, with surface temperature warmer than air temperature. Note: This could vary at different times of year in different locations. Students could present a reasonable explanation for the surface being colder than the air above early in the morning.
- Students explain that the ground is warmed by the Sun, which then warms the air above it.

Question 8 Rubric | **Rubric Measures:** Students identify that surface temperatures are warmer than the air temperatures above the surface, and they explain this concept using ideas about heating of the surface by the Sun, followed by heating the air above the surface.

	Emerging ⁸ -1	Developing-2	Approaching Proficiency-3	Excelling-4
PERFORMANCE	Graph shows an inaccurate or irrelevant prediction for surface temperature and reasoning using inaccurate, irrelevant, or ambiguous science ideas to support it.	Graph shows a partially accurate prediction for surface temperature and reasoning using partially accurate science ideas or incomplete science ideas.	Graph shows an accurate prediction for surface temperature and generally describes mechanisms that result in this pattern.	Graph shows an accurate and clear prediction of surface temperature and accurate and clear reasoning about the mechanisms resulting in the pattern.
LOOK FOR	<ul style="list-style-type: none"> A line below air temperature or no line at all. Reasoning about air being warmer than the surface. Focuses on times of day but does not explaining heating. 	<ul style="list-style-type: none"> A line that starts below and then goes above the air temperature line. A mix of accurate and incorrect ideas or vague reference to the Sun. 	<ul style="list-style-type: none"> A line drawn above the air temperature graph. Accurate, but vague, reasoning about the Sun heating the surface and mixing up light and heat, but with a mostly accurate idea. 	<ul style="list-style-type: none"> A line drawn above air temperature graph. A clear statement about sun causing heating of the surface first, which heats air above it.
SAMPLE RESPONSE	<p><i>[Student draws a line that does not follow the trend of the air temperature.]</i></p> <p><i>I expect it to get warmer because by 7:00 p.m., they have humidity of 90%, but from 11:30 a.m. to 4:30 p.m., I expect it to get cooler.</i></p>	<p><i>[Student draws a line that follows the trend of the air temperature and is warmer than the air.]</i></p> <p><i>It heats and cools throughout the day. The surface would be warmer because it's a solid.</i></p> <p><i>The Sun is going to rise and the ground will get hotter.</i></p>	<p><i>Correct graph and responses.</i></p> <p><i>The ground is always warmer than the air, OR the ground heats the air above it.</i></p> <p><i>The surface <u>absorbs the heat</u>, so it's always hotter on the surface than the air.</i></p> <p><i>Since the solid objects cool and heat up faster than the surrounding air, they <u>absorb more heat than air</u>, so the surface is hotter than air.</i></p>	<p><i>Correct graph and responses.</i></p> <p><i>The ground surface is always more directly hit by sunlight and usually heats up faster (than the surrounding air).</i></p> <p><i>I drew the surface temperature higher than the air temperature because the surface is absorbing more direct sunlight than it is reflecting into the atmosphere.</i></p>

⁸ If the student provides no assessable evidence (e.g., "I don't know" or leaves the answer blank), then that student response cannot be evaluated using the rubric.

Question 9 Rubric | **Rubric Measures:** Students identify a sudden drop in temperature and rise in humidity as conditions for a precipitation event.

PERFORMANCE EXPECTATION	ALIGNMENT TO NGSS DIMENSIONS 	PERFORMANCE OUTCOMES	ALIGNMENT TO PROMPT/CRITERIA IN PERFORMANCE ASSESSMENT
<p>ESS2-4: Develop a model to describe the cycling of water through Earth’s systems driven by energy from the Sun and the force of gravity.</p>	<p>SEP: Analyze and interpret data to provide evidence for phenomena.</p> <p><i>DCI:</i> Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land.</p> <p>Global movement of water and its changes in form are propelled by sunlight and gravity.</p> <p>CCC: Patterns in rates of change and other numerical relationships can provide information about natural and human-designed systems.</p>	<p>Analyze and interpret patterns in temperature and humidity data to explain why a storm occurred.</p>	<p>9. Use the temperature and humidity data in the graphs above to explain why it rained in the afternoon.</p>

Correct Answer

- Students describe how sunlight warms Earth’s surface, causing air above it to warm up as well as water to evaporate. This leads to moist, rising air.
- Students explain that there was a decrease in temperature and an increase in humidity, which are necessary ingredients for a storm.
- Students explain that the decrease in temperature causes moisture in the sky to condense and precipitate.
- Students explain that humidity needs to be high for a storm to form, so a quick increase in humidity indicates clouds or storms forming.

Question 9 Rubric | Rubric Measures: Students identify a sudden drop in temperature and rise in humidity as conditions for a precipitation event.

	Emerging ⁹ -1	Developing-2	Approaching Proficiency-3	Excelling-4
PERFORMANCE	Explanation uses irrelevant, minimal, or inaccurate science ideas about changes to both temperature and humidity as they relate to the afternoon storm and reasoning connecting the cause/s to the phenomenon is irrelevant, missing, or ambiguous .	Explanation uses partially accurate and relevant science ideas about one or both temperature and humidity as factors influencing the storm formation. Reasoning connecting the cause/s to the phenomenon is irrelevant, missing, or ambiguous .	A. Explanation uses accurate and relevant science ideas about one or both temperature and humidity as factors influencing the storm formation. Reasoning connecting the cause/s to the phenomenon is vague or general and doesn't explain how the two work together to explain storm formation. OR B. Explanation uses accurate and relevant science ideas about either temperature or humidity as the factor relates to storm formation and fully connects to the cause of the afternoon storm, but it <i>does not</i> connect the second factor to the afternoon storm.	Explanation uses accurate and relevant science ideas about both temperature and humidity AND reasoning connects the cause/s to the afternoon storm and explains how the two work together to result in the storm forming.
LOOK FOR	Incorrect pattern: <ul style="list-style-type: none"> Air temperature decreases (it actually increases and only decreases right at the storm). Humidity decreases (this happens at first, but humidity has to be high for the storm). Using a cold front in their explanation. 	Mostly correct pattern for part of the day: <ul style="list-style-type: none"> Rising or warm temperatures are needed. Rising or increasing humidity is needed. 	Correct pattern throughout the day: <ul style="list-style-type: none"> Air temperature increases and only drops around the time of the storm. Humidity initially decreases, then increases right before the storm. 	Correct pattern throughout the day: <ul style="list-style-type: none"> Air temperature increases and only drops around the time of the storm. Humidity initially decreases, then increases right before the storm. Reasoning that explains: <ul style="list-style-type: none"> How time and warm temperature lead to moist rising air. How a drop in temperature leads to condensation. How high humidity is needed for storm formation.
SAMPLE RESPONSE	<i>As the area was colder, the temperature was just right to make the storm.</i> <i>Because there was less humidity and higher air temperature.</i> <i>Because it cannot hold water so it rains.</i>	<i>The temperature goes down quickly and leads to humidity and clouds rising.</i> <i>The weather changes caused the thunderstorms because based on temperature there are different reactions to how hot or cold it is and how high or low the air pressure is.</i> <i>Humidity went up and air temperature went down.</i>	<i>When the temperature drops all of a sudden, it's not able to hold the cloud, so the cloud must precipitate, causing the thunderstorm.</i> <i>Since air temperature was cooling at the time and humidity was increasing, the conditions made it perfect for a storm to form. A storm needs cooler surface/air temps and high humidity as a basic.</i>	<i>Sunlight warms ground, causing air above it to warm and water to evaporate. This leads to moist, rising air.</i> <i>There was a decrease in temperature and an increase in humidity, which are needed for a storm. The cooler temperature causes water vapor in the sky to condense, forming clouds and precipitation. There needs to be high humidity for a storm to form, so a quick increase in humidity indicates clouds or storms forming.</i>

⁸ If the student provides no assessable evidence (e.g., "I don't know" or leaves the answer blank), then that student response cannot be evaluated using the rubric.